HUTCHINSON'S

SPLENDOUR OF THE HEAVENS

A Popular Authoritative Astronomy

EDITED BY

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(Secretary of The Royal Astronomical Society)

AND

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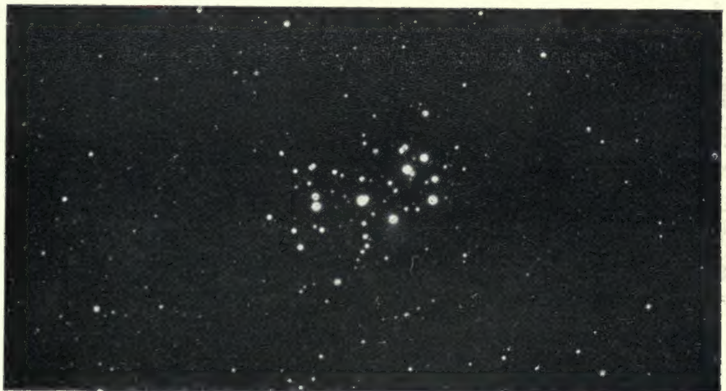

Photo by] [*W. H. Steavenson*

THE PLEIADES.

VOL. II.

Containing

524 Black and White Illustrations
and 13 Coloured Plates

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CORRIGENDA ET ADDENDA FOR VOL. II.

p. 571. The N.G.C. numbers in the legend of the bottom illustration (5128 and 5247) should be transposed. N.G.C. 5128 is upside down on p. 582 as compared with its presentation on p. 571.

p. 630. In bottom line, for *these* read *those.*

p. 688. In last line of legend to figure, for *plane* read *place.*

p. 691. In line 13 delete " and fasts."

p. 693. In last line but two, for *0·3* read *18.*
In last line but one, for *seconds* read *minutes.*
In last line, for *minutes* read *hours.*

p. 694. Near bottom of page divide paragraph after " Orthodox Church," not after " without further correction."

p. 706. Under figure, for *Goul* read *Gould.*

p. 729. (Illustration.) The term " German " must not be taken to imply that this stand is in any way a German model ; it is, on the contrary, an excellent example of British design and manufacture. *See* p. 740, lines 27–34, and also the illustrations on pp. 722 and 726. The terms " English " and " German " in this connection have been in common use for very many years to describe the two different arrangements of the polar and declination axes, and have long ceased to have any " territorial " meaning.

p. 741. Many writers use the terms " positive " and " negative " spherical aberration in the opposite sense to that here indicated ; *i.e.* " positive " for under-correction, and " negative " for over-correction.

p. 745. " Extra-focal images (IV)." In the first line of the description under this illustration the words " within " and " beyond " should be interchanged.

p. 772. Title of second illustration, for *Yerkes* read *Chicago.*

p. 812. In line 17 of second paragraph, for *easily* read *exactly.*

p. 818. In line 18, for *equatorial* read *polar.*

p. 928. The name of Dr. A. C. D. Crommelin, as compiler of the list of coming eclipses, should have been given.

p. 932. In the list of pronunciations and meanings of Star names, the following meanings may be added :—
Altair.—The Flying Eagle. (*Eagle* understood.)
Arcturus.—The Bear Guard, or perhaps Bear's Tail.
Deneb.—Tail.
Praesepe.—An alternative meaning is Manger. *See* p. 651 (legend).
Rigel.—Foot.

VOL. I.

p. 25. In the picture of Jai Singh's Observatory the artist has placed the Sun in the North. This is, of course, an impossible position in the latitude of Delhi.

CONTENTS OF VOL. II.

COLOURED PLATES.

ILLUSTRATIONS IN THE TEXT.

Illustrations in the Text.

Illustrations in the Text.

Photo by] [*H. F. Newall*

THE NEWALL TELESCOPE, CAMBRIDGE.

Printers:
SIR JOSEPH CAUSTON AND SONS, LIMITED,
9, EASTCHEAP, LONDON, E.C. 3.

THE PLANET SATURN.

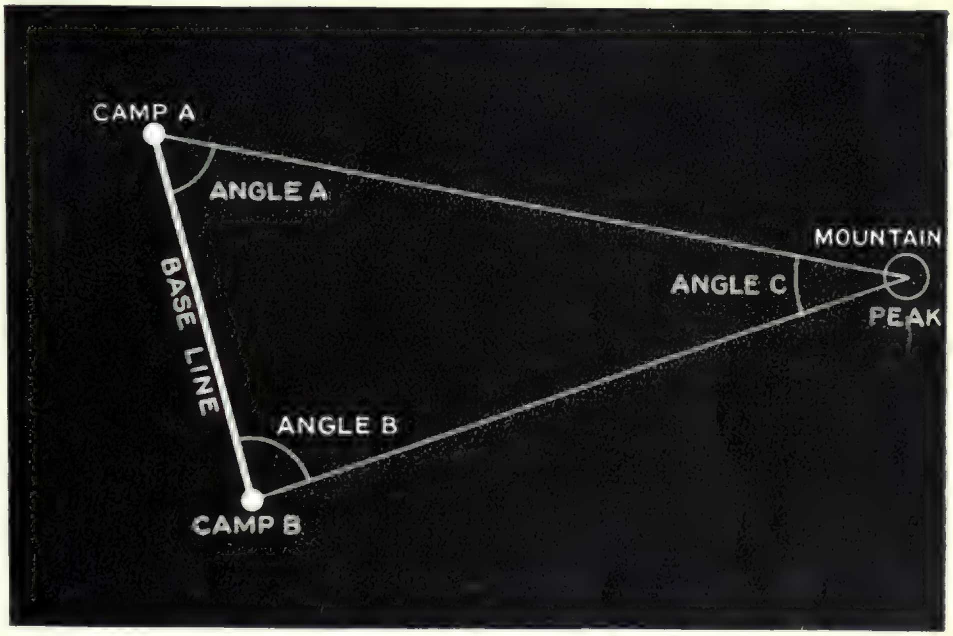
This illustration conveys a rough idea of the probable appearance of Saturn as seen with the naked eye from one of his satellites. The orbits of the latter lie nearly all close to the plane of the rings, which therefore are seen almost edgewise. From one of the inner satellites they would appear even more narrow and linear than depicted above. The globe of the planet is delicately coloured and generally exhibits a series of parallel dusky belts. The rings are almost pure white in colour. (See Chapter VIII.)

CHAPTER XI.

FINDING THE SCALE OF SPACE.

By Peter Doig, F.R.A.S.

In any science one of the most important requirements is the determination of numerical values. Astronomers have to face what seems at first glance an insuperable problem of this kind—the ascertainment of distances to which it is impossible by the nature of things to apply measuring gauges directly. The very earliest " watchers of the sky " believed all celestial objects to be situated at the same distance on the vault of the heavens, but the Greek thinkers began to assign relative distances to the Sun, Moon, planets and fixed stars. Aristarchus of Samos, who lived about 280 B.C., showed that the Sun must be at least nineteen times as far off as the Moon, which estimate is much below the truth, but was a step in the direction of positive knowledge beyond which there was no advance for a long time. The scale of space was not then known even in the very roughest fashion, however; the first crude solutions of the problem were reserved for the later and possibly less acute intellects of mediaeval times, and that only for such less remote celestial objects as those in the Solar System.



A SURVEYOR'S "TRIANGLE."

The surveyor who wishes to find the distance of an inaccessible point, such as a mountain peak, lays off and measures a base line between two camps. From one camp he measures with his theodolite the angle between the mountain peak and the other camp, and then goes to his other station and does similarly for the first camp and the peak. From these two angles and the measured length of the base line, the distances of the peak from the two camps can be easily calculated.

The process of finding the distance of a celestial object is essentially the same as is used by a surveyor when he desires to find the distance of some inaccessible object such as a mountain. In most cases measurement in the ordinary way with tape or chain is impossible because of the roughness of the intervening country, or because of the impossibility of attaining to the top of the mountain. For example, the summit of Mount Everest is as yet inaccessible, but its distance from a hill station, such as Darjeeling, can be found with great accuracy. The surveyor proceeds as follows.

From a camp at A the distance is first accurately measured off to camp B, the line between being described as the " base line." Setting up his theodolite at A he measures the angle between the camp B and the mountain peak and then goes to camp B and measures the angle B similarly. He then knows the length of one side of the triangle and the sizes of two of its angles, and by a very simple calculation

can derive the third angle C and the distances from camp A or camp B to the mountain. The surveyor does not concern himself directly with the angle C but deals with distances so that he can "triangulate" an entire territory.

By a sustained process of connected triangles and accompanying astronomical observations for longitudes and latitudes, much of the Earth's surface has been mapped out and the shape and dimensions of our globe closely ascertained. As is well known the shape of the Earth is not truly spherical, but of a flattened spheroidal form, so that the diameter from pole to pole is 7,900 miles and across the equator 7926·7 miles.

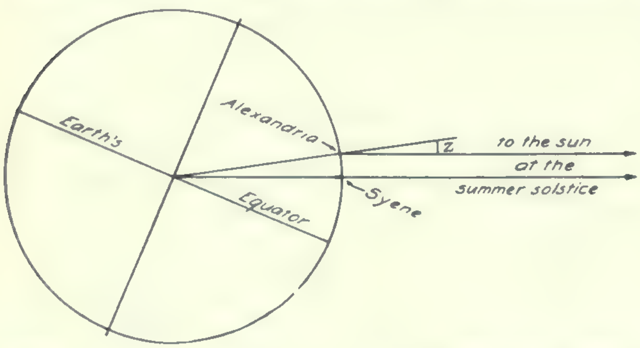
From, *"Adolfo Stahl" Lectures.*

THE WELL OF ERATOSTHENES.

This well, situated at Assouan (the ancient Syene) is said to be the one used by Eratosthenes in connection with his famous measurement of an arc of the meridian. From his observations he obtained the first reasonably correct value for the Earth's circumference and diameter.

The surveyor finds a base line of several hundred yards sufficient for determining most distances, but occasionally uses one as long as possible, of several miles length, so as to obtain an accurate measurement of a very remote object. The astronomer, however, requires a very much greater base line for the smallest of celestial distances. The nearest of the heavenly bodies is the Moon, of which the mean distance is 238,860 miles, and for the determination of the size of this great gap the astronomer finds a base line in the Earth itself. In this case there are two observatories, the distance between which is well known. The angle at the Moon and the sides of the triangle can be well determined and from them the distance between the centres of the Earth and Moon. The "parallax" of the Moon is half the angle which is contained between the lines connecting the extremities of the Earth's diameter and the centre of the Moon and is somewhat less than one degree (fifty-seven minutes approximately).

The same base line is used in finding the scale of the Solar System. As the diameter of the Earth is but 7,900 miles, we cannot get a longer base than that, and practical considerations limit it to about 7,000 miles. The Sun is more than 13,000 times this distance away and the triangle concerned is extremely long and narrow, with the angle at the Sun smaller than sixteen seconds of arc. As a problem of surveying, the measurement of distance by direct observation of the Sun's position in the sky is not capable of more accuracy than about one part in thirty or forty.



From] *["Adolfo Stahl" Lectures.*

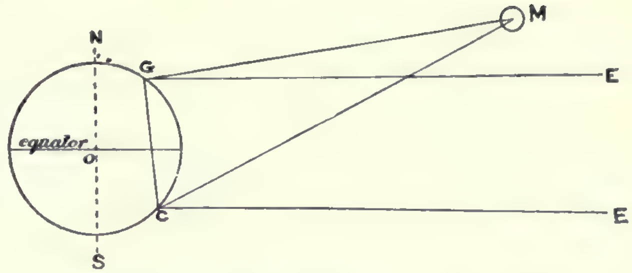
AN ANCIENT MEASUREMENT OF THE SIZE OF THE EARTH.

This diagram illustrates the method employed by Eratosthenes. Observations of the Sun's altitude at Alexandria and Syene respectively gave the number of degrees of latitude (shown by the angle Z) between the two places. The actual distance being known in units of linear measure, it was easy to calculate the length of the complete 360° comprising the Earth's circumference.

If the stars could be observed close up to the Sun and simultaneous observations made of its apparent position among them as seen from the ends of our base line, the problem would be simple and capable of considerable accuracy with little effort. The Sun would appear differently placed with reference to the vastly remoter stars, a nearer body having a shift (Greek, "parallaxis")

relative to objects farther away. We cannot see stars close up to the blazing disc of the Sun owing to the overwhelming atmospheric effect of its radiance, but on rare occasions the planet Venus passes across its face and at these times has a parallax relative to the Sun's disc.

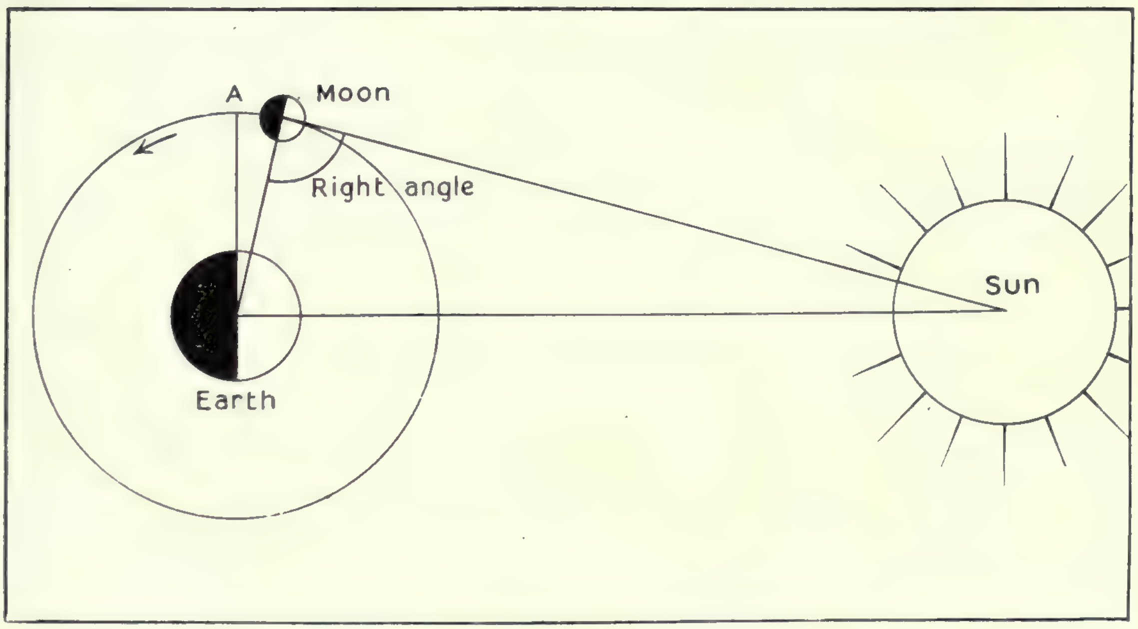
Two observers on the Earth at *a* and *b* (*see* page 452), will see the planet projected on different parts of the Sun's disc. The observer at *b* will see the planet cross along the line CD, while the observer at *a* will see it traverse the Sun's face along the chord FG. When Venus is between the Earth and the Sun (in "inferior conjunction") its distance from the Sun is to its distance from the Earth in the proportion seventy-two to twenty-eight. This is known from the law discovered by Kepler, which states that the cubes of the distances between the planets and the Sun are proportional to the squares of their periods of revolution about him, and it was discovered by that great astronomer independently of any knowledge of the actual distances.



MEASURING THE DISTANCE OF THE MOON.

This diagram shows a method of measuring the distance of the Moon. G and C represent two observatories (say Greenwich and the Cape of Good Hope). M is the Moon, GE and CE are the directions of the equator on the sky at the two places. The difference of the angles MCE′ and MGE, which is the same as the angle GMC, is measured and from this angle together with the known rectilinear distance GC, the distance of the Moon is derived, just as by a surveyor in the case of an inaccessible terrestrial object.

The base line or rectilineal distance between *a* and *b* is known, and as the ratio between this and the line *xy* is twenty-eight to seventy-two, *xy* can be computed. The ratio of the lengths of the chords CD and FG is got from the observed time of crossing of Venus across the Sun and it is then possible to calculate the size of the Sun's disc itself by means of the known distance *xy*. The angular diameter

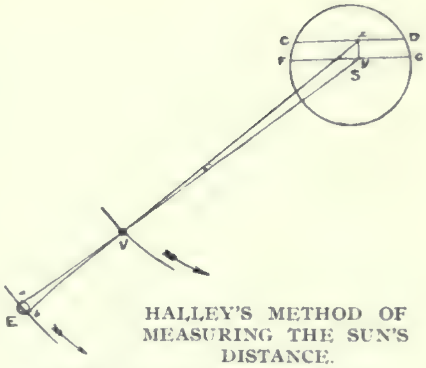


"PHASE" METHOD OF MEASURING THE SUN'S DISTANCE.

An ingenious method of measuring the Sun's distance in comparison with that of the Moon was devised by Aristarchus (B.C. 280). In the above diagram (not to scale) the Moon is shown at the instant it would look half Full from the Earth. The angle at the Moon must then be a right angle Aristarchus estimated that the First Quarter of the Moon was about twelve hours shorter than the Second Quarter; so that the Moon was six hours in going to A, or about four degrees of its orbit. From this he deduced that the distance of the Sun is about nineteen times that of the Moon, which is much too small; the method failing badly because of the mountainous character of the Moon's surface, making it impossible to estimate accurately the instant when the Moon is half Full.

of the Sun is measured, and to find its distance from the Earth we have simply to calculate the distance at which a body of known size subtends a given angle.

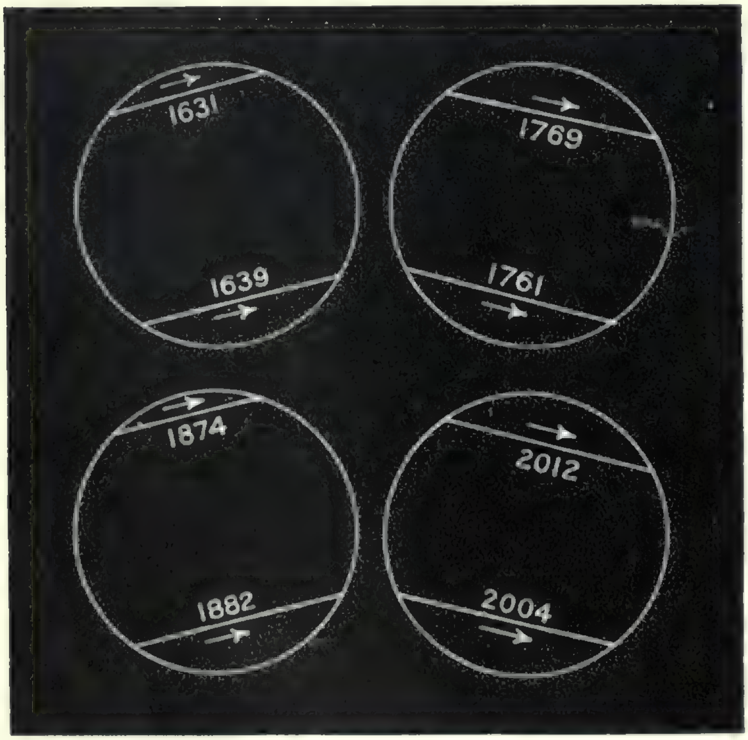
Certain corrections have to be made for the motion of the observers at *a* and *b* due to the Earth's movement in its orbit and to its rotation. The method described is due to Halley (1656–1742) who suggested it at a time when it was impossible that he should live to see it carried out. Another method used on the occasion of a transit of Venus was suggested by Delisle (illustrated on page 205), but need not be further described, particularly as either method is no longer looked upon as a good one for determining the solar parallax. Owing to various causes, chief among which is the so-called " black drop " and also a troublesome ring of light round the planet evidently produced by its atmosphere (*see* page 211), which render it almost impossible to estimate accurately the times of entry and exit of the planet on the solar disc, other methods are now more relied on. In any case the method cannot be again applied until the year 2004, which sees the next transit of Venus.



HALLEY'S METHOD OF MEASURING THE SUN'S DISTANCE.

The diagram illustrates Halley's method of utilising the transit of Venus for measurement of the Sun's distance. The observers on the Earth at *a* and *b* will see Venus cross the Sun's disc along the chords FG and CD respectively. The relative length of these chords is got from the times taken in the transit. The relative distances of Venus and the Earth from the Sun being known, and also the distance between *a* and *b*, the length *xy* can be computed and from that, and the ratio of the chords FG and CD, the actual diameter of the Sun is obtained. The angular diameter of the Sun is measured, and to find its distance from the Earth we have simply to calculate the distance at which a body of known size subtends a given angle.

Another method, which has been employed with great success and a higher degree of accuracy, depends upon the measurement of the parallaxes and distances from the Earth of some of the planets situated at greater distances from the Sun than the Earth. By Kepler's Law above described, the dimensions of all the orbits of the planets in the Solar System are as a consequence derivable. Mars and some of the minor planets or " asteroids " have been utilised in this way when at " opposition," *i.e.*, on the opposite side of us from the Sun and therefore crossing the meridian (due south) at midnight.



PAST AND FUTURE TRANSITS OF VENUS.

Transits of Venus occur in pairs, with eight years between each transit of the pair, and intervals of 105½ or 121½ years between the pairs. The method of measuring the solar parallax by means of the transits was employed on the occasions of the Eighteenth and Nineteenth Century transits, but it is doubtful if those of the Twenty-first Century will be similarly utilised, as better methods are now known.

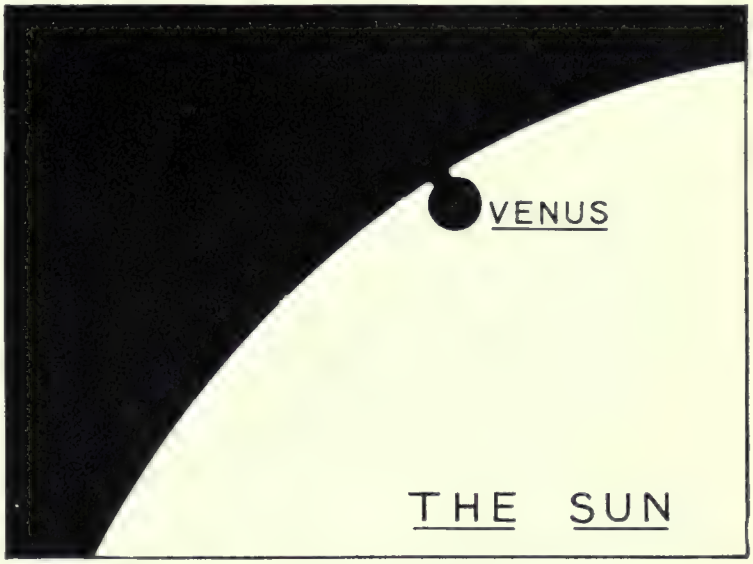
The parallax of the planet observed can be determined in the same way as that of the Moon, either by observations at two distant observatories, or by a single observer who utilises his displacement by the Earth's rotation to provide a base line. The actual measurements involved are the angular distances separating the minor planet from the background stars among which it is apparently

situated. These measurements have been made by an instrument called the heliometer, or by photography.

The heliometer consists of a telescope which has its object-glass divided into halves along a diameter. One half can slide along the other and thus produce two separable images. By movement of the two halves the images of two stars can be superposed in such fashion as to give very accurate measurements of distance between them or between a minor planet and a star, the shift of the parts of the object-glass being regulated by finely divided screws, one turn of which is equal to a certain small angle on the sky.

The great advantage of the photographic method, which is otherwise at least equally accurate, is that the astronomer is rendered much more independent of continued fine weather and clear skies. A photograph can be made in two or three minutes, and with a comparatively short break in the clouds far more valuable material can be got than by a whole night's heliometer work, for the photograph once secured can be measured and discussed at leisure by day or during cloudy nights.

The minor planet which is most valuable for this purpose is Eros, discovered in 1898, for which, although it is a very small body, probably not more than twenty miles in diameter, one would willingly barter the remaining hundreds of similar bodies. This is because it moves in a very remarkable orbit (illustrated on page 76) lying for the most part within that of Mars, very eccentric (*i.e.*, departing largely from a circle towards an oval shape) and approaching the Earth on favourable occasions to within about 15,000,000 miles when it has a large apparent shift or parallax with reference to the background of fixed stars.



THE "BLACK DROP."

It was expected by Halley that it would be possible to observe the instant of contact between the disc of Venus and the edge of the Sun within about a second of time. Unfortunately, the formation of a "black drop" takes place instead of a round disc neatly touching the edge of the Sun, the time of real contact being doubtful by as much as ten or fifteen seconds.

A close approach took place in 1900, but not until 1930 and 1937 will there be similarly favourable opportunities again. The 1900 "opposition" was used to obtain the most accurate value for the solar parallax as yet derived. By co-operation of a number of observatories using visual and photographic means a value of the solar parallax (or angle subtended at the Sun's distance by the Earth's semi-diameter) was obtained of

8·80 seconds of arc.

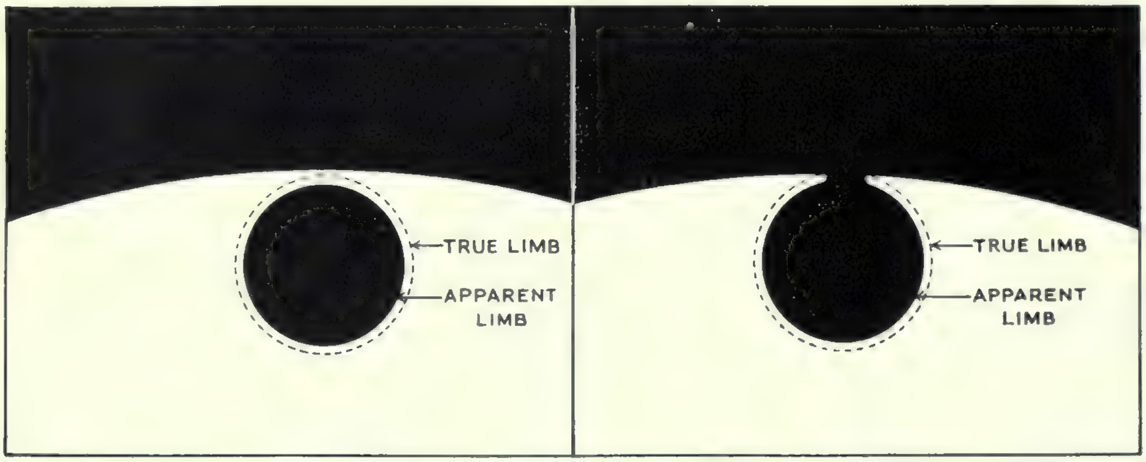
This corresponds closely to a mean distance of the Sun of 92,900,000 miles, which is probably correct within about 150,000 miles either way; according to very recent work, however, this parallax may be rather on the large side.

There are reasons for believing, however, that the most accurate value of this fundamental constant of Astronomy will be obtained by other and less direct methods. Some of these are of sufficient interest to be briefly referred to.

One general method is by the disturbing effects of the planets' gravitation on each other's motions, or of the Sun on the Moon's movements. Another depends on the mutual disturbances of the Earth

and Moon. The Earth's centre revolves in a small orbit round the centre of gravity of the Earth-Moon system. From the measured distance of the Moon and the ratio of its mass to that of the Earth, this orbit is found to have a radius of about 3,000 miles. As a result of the Earth's motion in this small orbit the Sun appears periodically displaced to one side or the other in its apparent yearly circuit of the sky, from the place he would occupy if the Earth were not thus disturbed by the Moon. The consequent angular displacement of the Sun having been measured, astronomers then learn the angle which 3,000 miles subtends at the Sun's distance, and from that can derive the distance by a simple calculation.

Another way of measurement of the scale of the Solar System has been derived from observation of Jupiter and his family of moons. When that planet is farthest from the Earth, on the other side of the Sun, there is an apparent delay in the times of the eclipses of his moons by the shadow of the planet compared with those occasions when the Earth and Jupiter are on the same side of the Sun, and therefore closer together by something like the width of the Earth's orbit. This was an unexplained phenomenon until the Danish astronomer Römer suggested in 1675 that it was due to the time taken by light to travel over the additional space. By experimental work with rotating mirrors and other



Drawings by] [*W. H. Steavenson.*

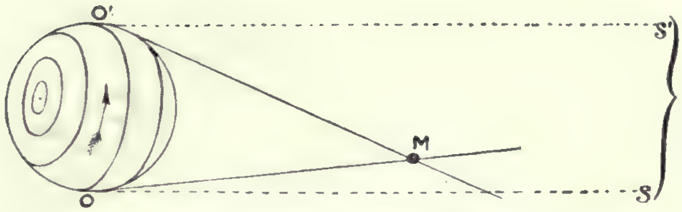
EXPLANATION OF THE "BLACK DROP."

When Venus is projected wholly within the Sun's limb the edge of her disc is encroached upon to an appreciable extent by the effects of irradiation and diffraction, so that she appears somewhat smaller than she really is. When, however, her true limb is in contact with that of the Sun the causes of this encroachment are no longer operative at that point, and we see a portion of her disc that was not seen before. This naturally appears in the form of an excrescence, and is known as the "black drop."

devices the velocity of light has been found to be 186,325 miles per second, and from the delay in the times of the eclipses of Jupiter's moons the diameter of the Earth's orbit can be deduced.

The knowledge of the velocity of light can also be applied to the problem of the Sun's distance by means of the phenomenon known as the "aberration of light." As a result of the fact that the propagation of light is not instantaneous, a star is slightly displaced from its true position in the sky. Each star appears to revolve once a year in a small elliptic path about its average position. One situated in the plane of the Earth's orbit merely oscillates on either side of a mean position and the breadth of the ellipse grows until it becomes a circle at the pole of the ecliptic.

The fact that the velocity of the Earth in its orbital motion round the Sun forms a sensible fraction of the velocity of light is the cause of this aberration, which may be understood by a simple illustration. When an object is let fall down the centre of a vertically disposed tube, it will go straight to the bottom without touching the side, if the tube is at rest. If a forward movement is given to the tube, however, the object would only pass down its centre without touching the side providing the tube were inclined at an angle. So it is with light coming from a star and passing down the tube of a telescope on a moving Earth. The telescope has to be pointed slightly away from the true direction of the star.



PARALLAX OF A MINOR PLANET.

The distance of a minor planet (M) from the Earth is found by measuring its position with reference to the background of fixed stars (S and S'). To observers at O and O′ (or to a single observer carried by the Earth's rotation from O to O′ the planet and the stars behind it have a different configuration, and from this apparent displacement and the known relative distances of the planet and the Earth from the Sun, the solar parallax can be found with more accuracy than by the Transit of Venus method.

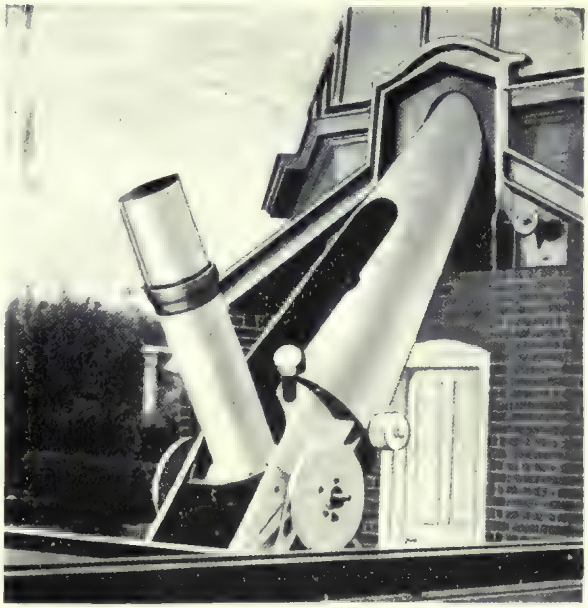
When the small ellipses are measured, the angle is found to be somewhat less than twenty and a half seconds of arc. By a simple calculation it is found that the velocity of light must be very nearly 10,000 times the speed of the Earth in its orbit, which thus comes out at about eighteen and a half miles per second. The circumference of the orbit in miles is therefore eighteen and a half times the number of seconds in a year and the semi-diameter, or distance of the Sun, is easily deduced.

Another indirect method of ascertaining the distance of the Sun is based on investigations of the velocities of the stars in the line of sight as revealed by the displacements of the lines in their spectra. At one season of the year, the Earth in its orbital movement is approaching a star, while six months later it is receding from it. Determinations of these motions of approach and recession with reference to a number of stars can be made and an accurate knowledge of the Earth's orbital speed derived from which the circumference and radius of the orbit are calculated. This method is susceptible of very great accuracy and increasing precision in the solar parallax value, as instrumental means improve and greater numbers of stars are utilised.

The same method has recently been applied to the changing velocity of the Earth itself. As the orbit is eccentric, the Earth is sometimes approaching the Sun (July to December) and sometimes receding from the Sun (December to July). These motions of approach and recession are shown in the displacements of lines in the Solar Spectrum, and when they are measured and discussed the scale of the orbit can be calculated. A similar method can also be applied to the radial velocities of the other planets.

The space which has been occupied in the foregoing discussion is justified by the very great importance of the problem of the Sun's distance. It is the fundamental datum of Astronomy—the unit of space, any error in the estimation of which is multiplied and repeated in many different ways, both in the dimensions of the Solar System and in those of the universe in general. The number which represents it is involved in almost every calculation of distances or masses, of sizes and densities either of planets or their satellites, or of the stars. Its determination has been referred to as one of the noblest problems of the science, and great expenditure of human effort and wealth has been made in attempts at its solution.

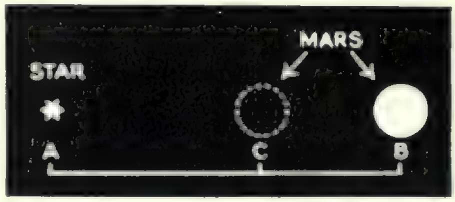
It is also among the most difficult tasks of the astronomer, involving as it does, in the direct methods, an attempt to measure an angle



SHEEPSHANKS EQUATORIAL, CAMBRIDGE OBSERVATORY.

This telescope was used very successfully in the determination of the solar parallax by photographs of Eros in 1899 and 1900. It is a modification of the "coudé," or elbowed, type of equatorial. The tube itself acts as the polar axis, so that the eye end (inside the building) remains stationary, but for rotation. This makes observation very comfortable and convenient.

about equal to that subtended by a halfpenny 2,000 feet from the eye, within about a thousandth part of its value. The scale of the entire Solar System follows very simply from the relation between periods of revolution and distances already mentioned, and in the case of the planet Neptune, we have the largest distance from the Sun which is thus directly derived—about thirty times the distance of the Earth from the Sun, an enormous gap over which the sunlight takes over four hours to pass, although the speed of light is such as would encircle the Earth's equator more than seven times in a second!



[W. H. Steavenson.

"PARALLACTIC" SHIFT OF MARS.

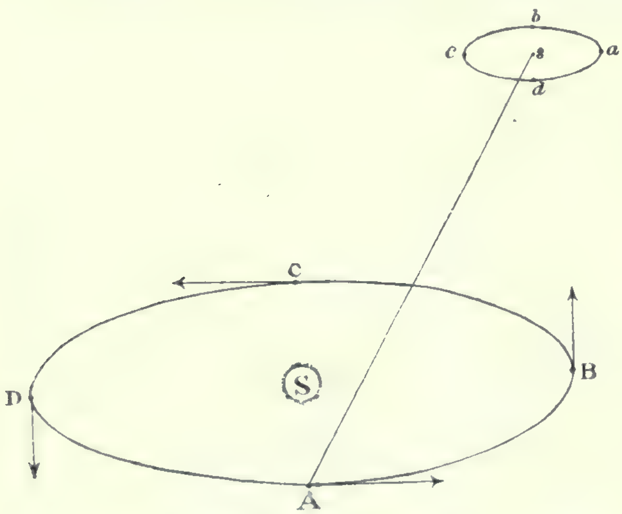
When Mars is close to the Earth his apparent position among the stars varies with the position of the observer on the Earth, or with the motion given to a single observer in a few hours by the Earth's rotation. The amount of shift (BC) in relation to a comparison star (A) gives a measure of the distance of the planet, after taking into account the distance moved by the observer.

Great as this is, it pales into insignificance beside the distances of the stars. When we come to the investigation of stellar remoteness no base line on the Earth is long enough, and we must use something much greater. The Earth makes this base line for us in its orbit round the Sun, and, large as it is, it is all too small for the purpose.

If the position of the star chosen for the investigation is determined in the sky as accurately as possible, say in the month of March, and then again after an interval of six months in September, the other end of the base line of 185,800,000 miles will have been attained, and if a difference is found in the positions as observed, the star's distance can be found. The parallax of a star is the angle made at the star by the radius of the Earth's orbit, or, to put it in another way, is the angle which would be occupied by a line 92,900,000 miles long at the Sun when seen from the star in question.

The slight movement in the position of the star is found by measures between it and fainter and probably more distant stars, though this is an assumption which is not always true, as is proved by the occasional *negative* results for parallax, which indicate either that the chosen star is really farther away than the average of the fainter comparison stars used, or that the parallax is too small to be within the limits of error in the measurements.

The determination of stellar parallax is comparatively simple but for the extreme minuteness of the quantities concerned. An idea of their smallness may be gained from the statement that if two railway lines starting in London, met in Newcastle instead of keeping parallel all the way, the angle between them would be of the order of magnitude to be measured in finding the distance of the nearest stars.



ABERRATION OF LIGHT.

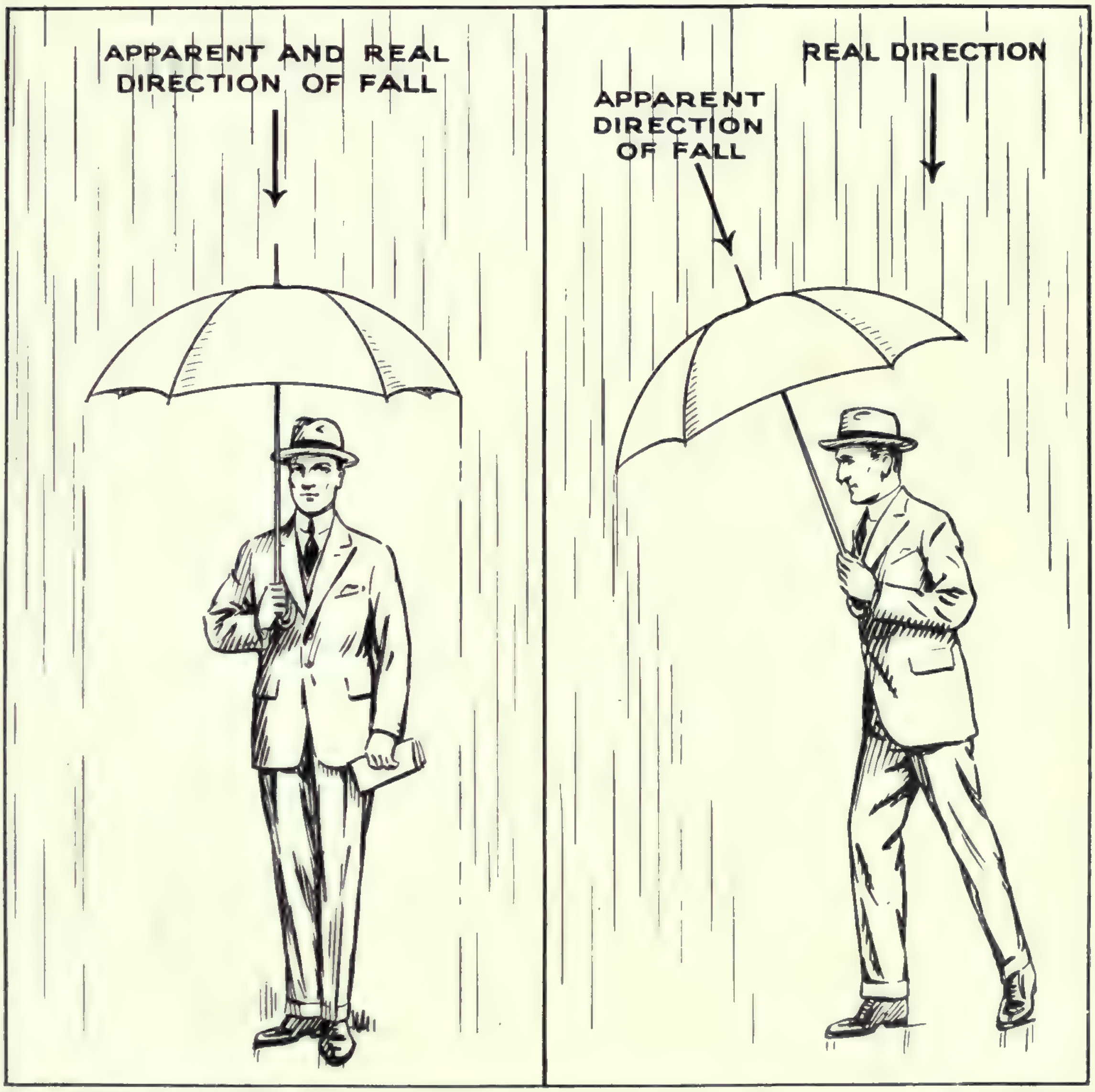
The diagram illustrates the effect on a star's apparent position of the Earth's motion in its orbit. A star *s* would appear in the direction A*s* if the Earth were at rest at A; actually it is seen at *a*, slightly ahead of its place, and in a year describes a small orbit on the sky, *abcd* corresponding to the points ABCD in the perspective view of the Earth's orbit.

There is no star known for which the parallax is as great as one second of arc; a second of arc is less than one millionth of the distance round the circumference of a circle, and is the angle subtended by a tennis ball about eight miles away or by a six-foot man at 250 miles distance.

Yet 92,900,000 miles looks smaller than this when seen from the distance of the very nearest of all the stars of which the parallax has been measured. This is "Proxima Centauri," a faint star situated near to and physically connected with the bright double star α Centauri, one of the brightest stars in the southern sky, which is itself the next

nearest known. The parallax of " Proxima " is seventy-nine hundredths of a second, corresponding to about twenty-four billion miles distance, or a light journey of four and one-tenth years.

The processes used in measuring these very small angles are similar to what has already been described for the minor planets, although the stellar parallaxes are very much smaller. The older methods used were those depending upon astronomical instruments which measure the places of the stars with great accuracy—the meridian circle, the micrometer and also the heliometer. So minute are the quantities to be measured that the instruments themselves, although made with graduated scales and screws of almost superhuman precision of workmanship, have to be tested for their errors which are then used as corrections to the results. Not only the instruments have to be analysed in



From a Drawing by] [*W. H. Steavenson.*

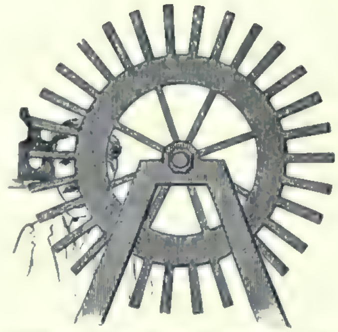
EXPLANATION OF " ABERRATION."

It is a familiar fact that the apparent direction of the drops in a shower of rain is altered by the motion of a person walking or running through it. The angle at which the drops appear to fall depends upon the ratio between the velocity of their descent and the motion of the observer. In the case of Light the speed of the Earth in its orbit is small compared with the enormous velocity of 186,000 miles per second, so that the change of apparent direction is small. But the principle is the same, and our telescopes (like the man's umbrella) must be directed slightly ahead of the place where the star would appear if we were stationary.

this way, however, but also the personal errors of the observers which vary from one individual to another.

The conditions under which the observations are made have to be kept the same as far as possible. Even after all these precautions there are outstanding discrepancies in the best results, which are often of the same order of size as the quantities to be measured. While these visual methods have given very valuable service, photography is to-day much the better for stellar parallax work.

If two photographs of the same region are taken six months apart, the shift of the " parallax star " can be measured with reference to a number of comparison stars, by means of a microscope. Minute precautions must be taken with this method also, as the quantities to be measured on the photographic plate are generally only a few hundred thousandths of an inch.

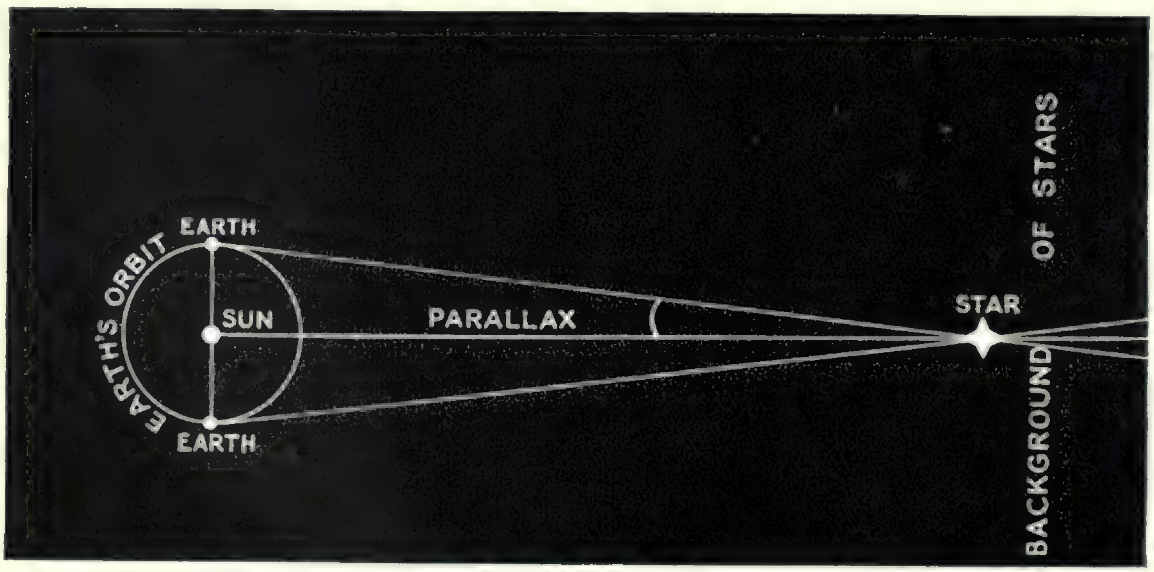


MEASURING THE SPEED OF LIGHT.

A toothed wheel, revolving rapidly in front of a lamp, was used by Fizeau to measure the velocity of Light. A distant mirror sent back the rays that passed between the teeth, and by noting the velocity of rotation whereby the returning ray could just be caught on the next (or some later) tooth, the speed at which the light had travelled could easily be deduced.

To form an idea of what is now being done with large photographic telescopes in stellar parallax work, the reader may imagine two plumb-lines five feet apart. They are sensibly parallel but of course actually would meet, if produced, at the centre of the Earth. The angle between them is only one-twentieth of a second, yet angles of this size are now being measured in photographic work with an accuracy of nearly one-fifth of their size, *i.e.*, one-hundredth of a second of arc ! About fifty years ago the then Astronomer Royal (Sir George Airy) referred to an angle ten times this size as the " smallest thing in the world " ; considerable progress has evidently been made !

A great deal of care is required in taking the photographs and in measuring them. The small images of the stars have to be as accurately round as possible so that the centres can be estimated to within a fiftieth or a hundredth of their diameters. To make for the necessary accuracy, the telescope must be guided as perfectly as possible in following the stars in their motion across the sky due to the Earth's rotation. The photographic image of the parallax star should not be larger than the comparison stars, and as it is usually brighter, this is effected by the use of a rotating shutter partly covering the image



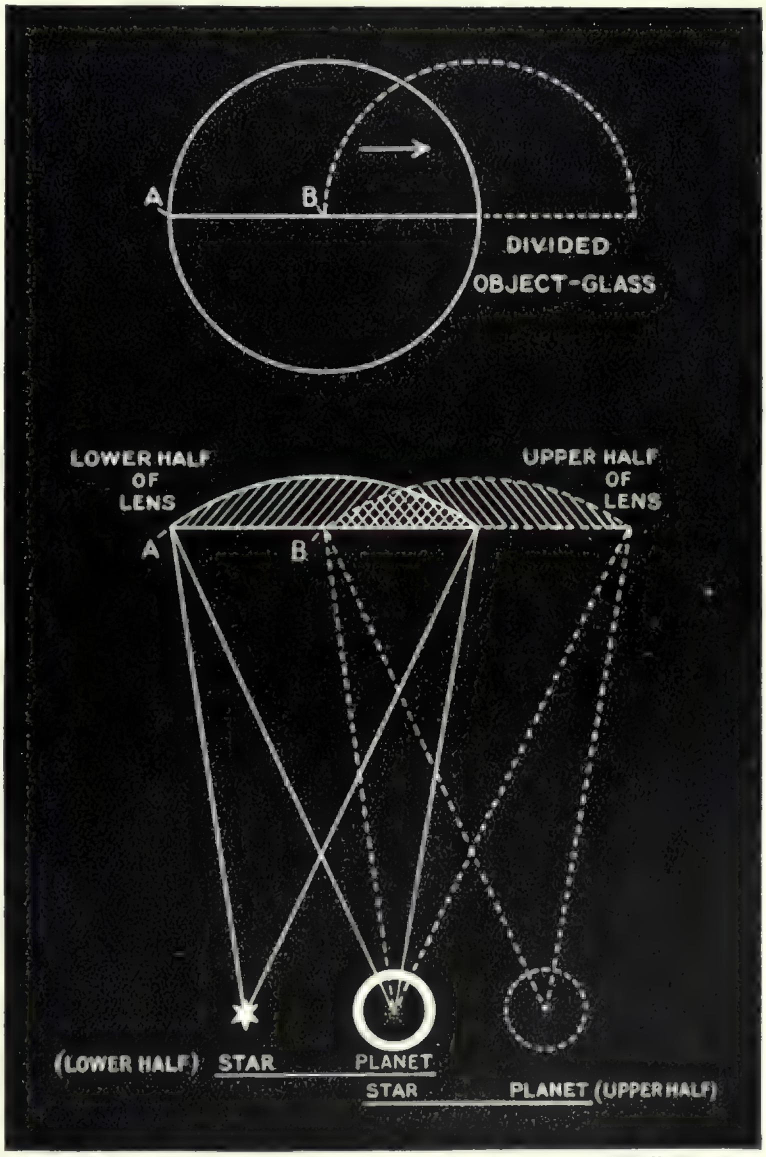
PARALLAX OF A STAR.

The 185,800,000 miles width of the Earth's orbit makes a base line from each side of which a star is observed at an interval of six months. Half the angular displacement with reference to the fainter and remoter background stars is called the " annual relative parallax."

of the star and thus lessening the quantity of light received from it on the photographic plate, or by local chemical treatment of the plate or other means.

The best modern parallax determinations made by the most skilful observers employing powerful telescopes (ranging from 20 to 100 inches diameter) are yielding reliable parallaxes for stars up to 200 light-years distance, corresponding to a parallax of sixteen-thousandths of a second of arc. Greater distances than this are not at present accurately measurable directly, owing to the unavoidable errors of observation, which are then comparable in size with the parallaxes themselves. In short, the base line of the Earth's orbit is too small for the direct measurement of greater distances with present instruments and methods. Several observatories are devoting themselves largely to this line of work, however, and as a result of their labours there are now over 1,200 reliable parallaxes measured in this way, which number is increasing at the rate of about 200 per annum.

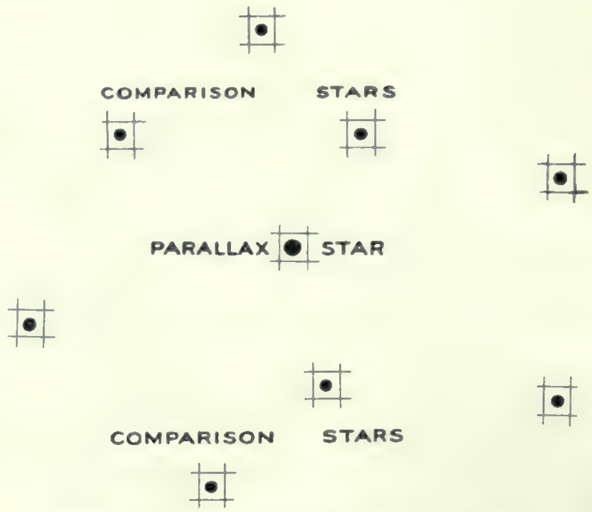
It may be well at this stage to explain what the astronomer means when he estimates the accuracy of a result by what he terms its " probable error." It can be illustrated in a simple way. Let the reader suppose that he is given the task of measuring the length of a field with an ordinary foot-rule, and asked to get as accurate a result as possible. With this in view he will realise that a number of separate measurements of the field laboriously undertaken and then averaged will give a better result than one measurement however carefully performed. If he makes, say, twenty sets of measurements it will be found that no two of them will agree but that some are several inches larger or smaller than the average of the twenty.



Drawing by] [*W. H. Steavenson*

PRINCIPLE OF THE HELIOMETER.

The heliometer was devised originally for measuring the diameter of the Sun, whence its name. It has also been used for measuring angles which are too large to be readily compassed by the ordinary eye-piece micrometer. The object glass is divided into two portions, capable of sliding on one another. Each forms its own set of images, like a complete lens, and these images can be displaced with regard to one another by sliding the two halves of the object glass. The lower half of the diagram shows how, in measuring the distance between two objects, the two halves of the lens have to be relatively shifted through the same distance (AB) as that which separates the images of the objects. The distance AB is read off on a scale when the two pairs of images are separated to the extent shown.



STELLAR PARALLAX BY PHOTOGRAPHY.

Two photographs are taken, at an interval of several months, and in each case the position of the image of the near star is measured with regard to a number of fainter surrounding stars, which are presumed to be more distant. At Greenwich the method has been adopted of cutting fine lines with a diamond on a separate plate of glass near the position of each star. The glass plate is then used as a standard of reference, being placed in contact with each of the two photographs successively, the measures in each case being made relative to the engraved lines.

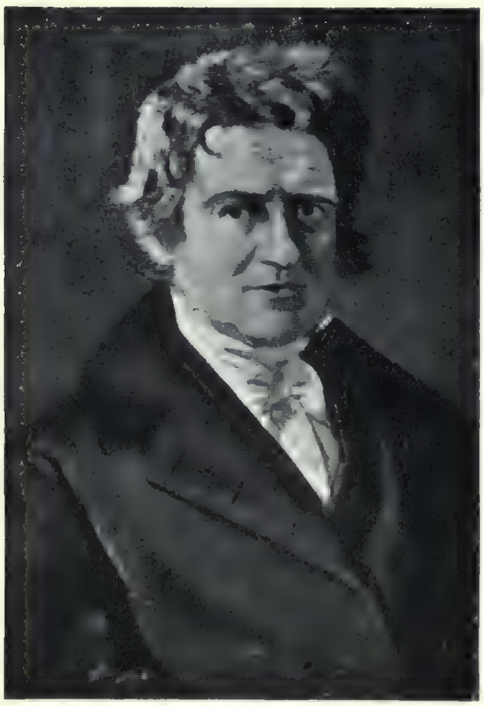
This average would be the most probable value for the length of the field, and from the deviations of all the separate twenty measurements a surveyor could calculate a quantity which he would call the " probable error " of the result. This quantity is to some extent a measure of the accuracy of the work. Manifestly a probable error based on a hundred measurements would be smaller than one got from twenty sets and one from twenty carefully-made measurements would be smaller than that derived from twenty not so precisely undertaken.

This probable error, however, is not necessarily the true measure of the correctness of the result. It is a measure of the *accidental* errors, but not of any error which may be constantly present, such as would be involved in the use of a foot-rule which was slightly too long or too short, or in some systematically defective manner of applying the foot-rule.

In the same way the astronomer's "probable errors " are not necessarily the true ones—there may be (or rather, there certainly are) " systematic errors " also. Both kinds of error are being lessened as time passes, by the use of better instruments and superior methods of work, but nevertheless are yet present to such an extent as to render of little value very small parallaxes of the order of one-hundredth of a second or so, when obtained by the usual direct methods of measurement.

Our twenty-five nearest neighbours are contained within a sphere with the Sun at the centre, across which light would take thirty-two and a half years to pass. It is probable that there are few, if any, others in this great volume. If we enlarge the sphere to sixty-five light-years diameter there are over 100 known, although there are very probably nearly another 100 more in this volume for which the distances are not yet determined, particularly in the southern skies, which are not yet so well explored for parallax as those regions dealt with by the more numerous northern observatories.

Many of these stars are binaries, two suns revolving in great orbits about a common centre of gravity. It is of interest to note that the number of binaries in the volume of space referred to, bears about the same ratio to the number which are single stars, as that found for the stars generally. In the twenty-five stars nearest to



From Bryant's " History of Astronomy."
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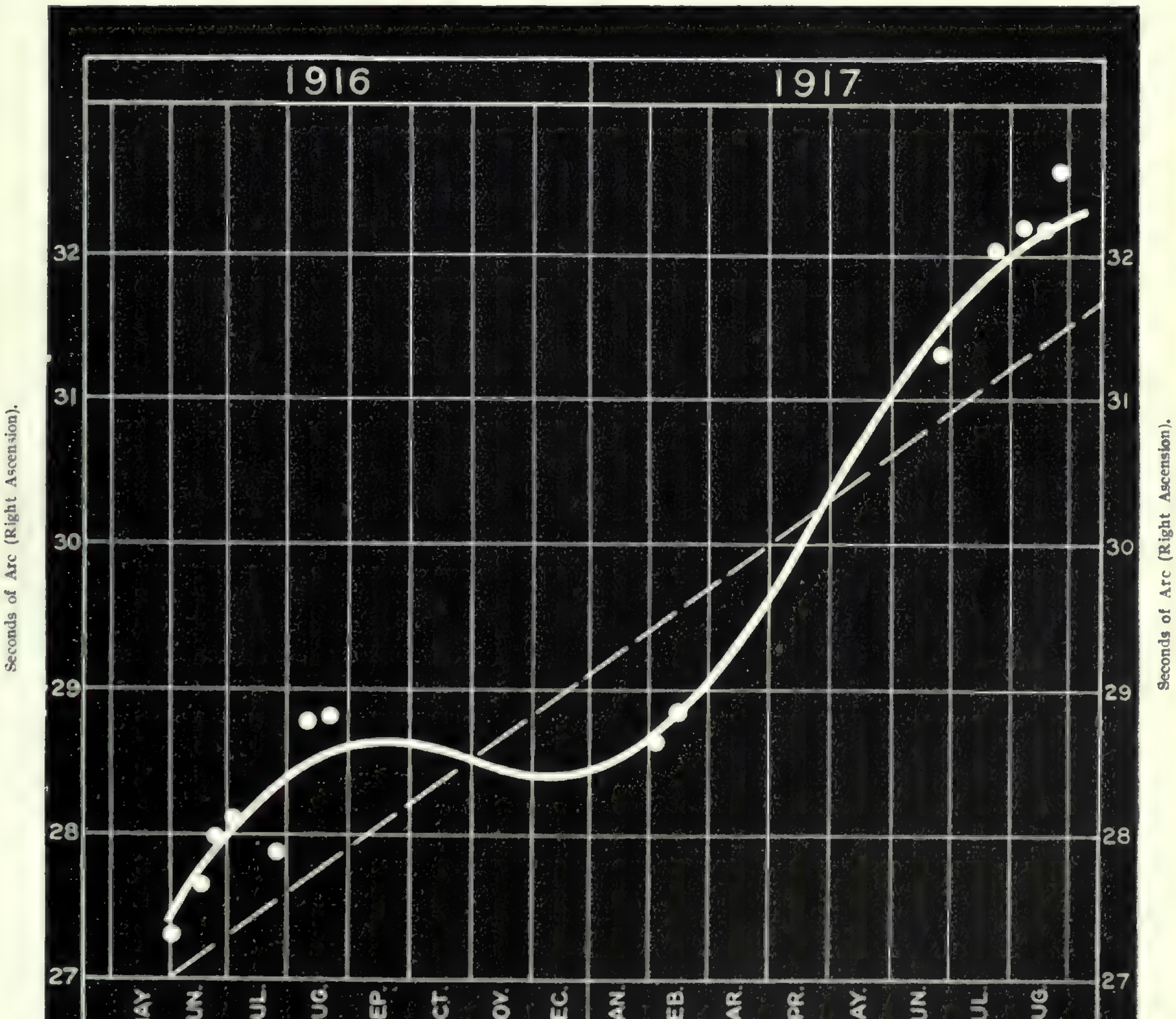
BESSEL (1784—1846).

To Bessel we owe the first reliable measure of a star's distance. His measurement of the parallax of 61 Cygni with the Konigsburg heliometer in 1838 marks the beginning of our accurate knowledge of the scale of the sidereal universe.

the Sun there is a great diversity of real brightness. The most luminous star among them is Sirius, which gives a light output about twenty-eight times that of the Sun, and the faintest is Proxima Centauri, which shines with only about one-seventeen-thousandth of the Sun's light. In a later section of this work will be found a description of the division of the stars by their luminosities or total light output, into two classes, the "giants" and "dwarfs." There are no stars which can be properly described as giants (although Sirius almost deserves the name) until a greater distance than the sphere containing the twenty-five nearest stars has been passed, the Sun itself being a dwarf star.

So far we have only dealt with the effect of the observer's motion, when carried round the Sun in the Earth's orbit, upon the apparent position of a star. For over 200 years, since Halley detected



PARALLACTIC SHIFT OF "PROXIMA CENTAURI."

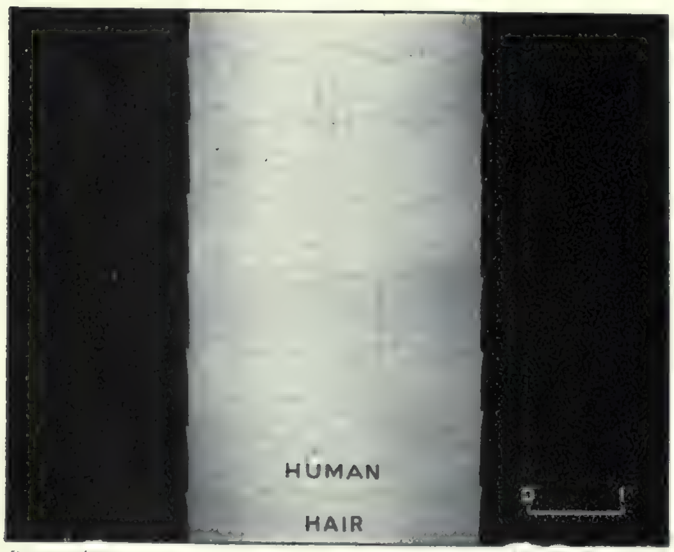
This diagram shows the effect of the swing of the Earth in its orbit round the Sun on the apparent position on the sky of the nearest star, Proxima Centauri. The angular distance from a neighbouring and very remote star is measured at intervals and plotted down. The straight dotted line shows these distances without the effect of the Earth's motion in its orbit: the waving line shows this effect, which repeats itself with a period of twelve months.

AN ANGLE OF ONE DEGREE.

To an observer at A the two stars on the right appear separated by just one degree, or one-three-hundred-and-sixtieth part of a circle. The inclination between the two directions appears small enough, but astronomers are accustomed to measure accurately angles as small as a hundredth of a second of arc. This minute angle is only one-three-hundred-and-sixty-thousandth of that shown in our illustration !

in 1718 the changes in position in the sky of Arcturus, Procyon and Sirius since ancient times, it has been known that the stars also are moving. When accurately determined positions of the stars, made at considerable intervals of time, are compared with each other, it is found that some have changed their position in the sky by appreciable amounts. This change in position is termed the star's " proper motion."

Although stellar proper motions are very minute, it is clear that after a sufficient lapse of time the familiar configurations in the heavens will be much disturbed except where the stars concerned are moving together. In the Plough, for example, the five intermediate stars of the seven are moving in approximately parallel lines, although the star at each end is moving in another direction. Thus there was no Plough for the men of the Stone Age, and there will not be one for our descendants thousands of years hence. Associated with the five stars mentioned are a number of others close to them in apparent position and also some scattered widely over the sky, of which the most notable is Sirius. These stars form a great cluster, the members of which are travelling together through space although separated by enormous distances.



Drawing by, *W. H. Steavenson.*

THE MINUTENESS OF PARALLAX MEASURES.

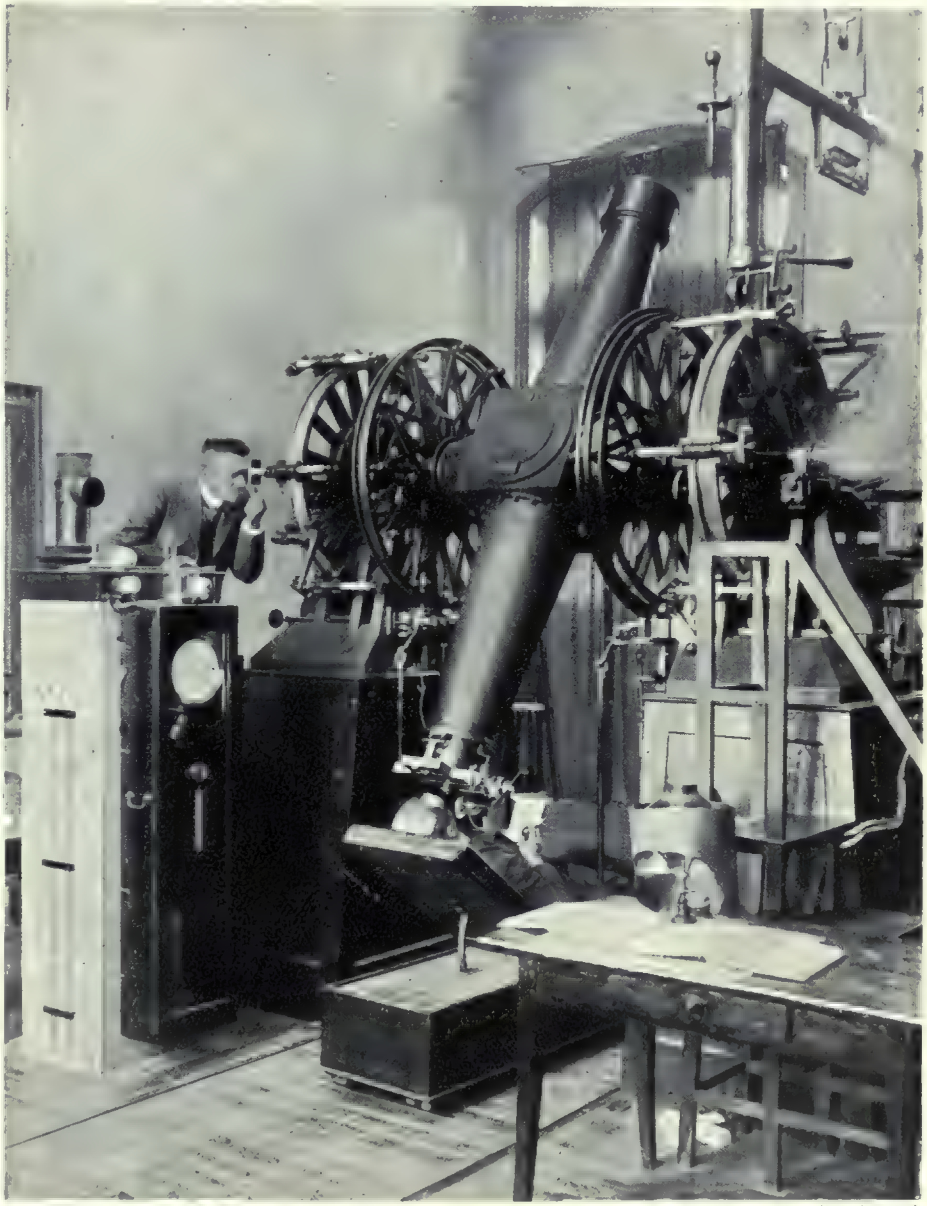
This illustration gives some idea of the minuteness of the quantities actually measured in determining stellar parallaxes by the photographic method. A second of arc on one of the Greenwich parallax plates is about one-third of the diameter of a single human hair ; and yet displacements of stars are measured correct to one-hundredth of this minute angle.

By a similar community of proper motion astronomers have been able to recognise a number of groups, the Taurus cluster, the Pleiades, the stars in Orion, those in the Beehive (Praesepe), and a numerous scattered group of stars of great luminosity in the constellations Scorpius and Centaurus. The members of these clusters are physically related and the methods of estimating their distances will be referred to later.

When the proper motions of a number of stars distributed over the heavens were studied, it was noticed that while there was a considerable amount of random movement in all directions, yet there was a strong tendency for the motions to be directed towards a particular point on one side of the sky and away from a point directly opposite on the other side. The astronomer who was

first to explain this as due to a motion of translation of the Solar System in space, was Sir William Herschel in 1783. His conclusion was that the point of the sky from which the stars appear to be separating is the one towards which we are moving, and that the opposite point to which the stars generally appear to converge was the direction from which we are receding in space.

The apparent motions of the stars are therefore made up of their own individual movements, combined with that of the Sun reversed. The earlier investigators, who corroborated Herschel's results as regards the direction of movement, could not determine the speed of translation. In order to do this the distances of the stars would require to be known so that the angular motions could be turned into linear movements.



From "Astronomy for All."] [By permission of Messrs. Cassell & Co., Ltd.

A MERIDIAN CIRCLE.

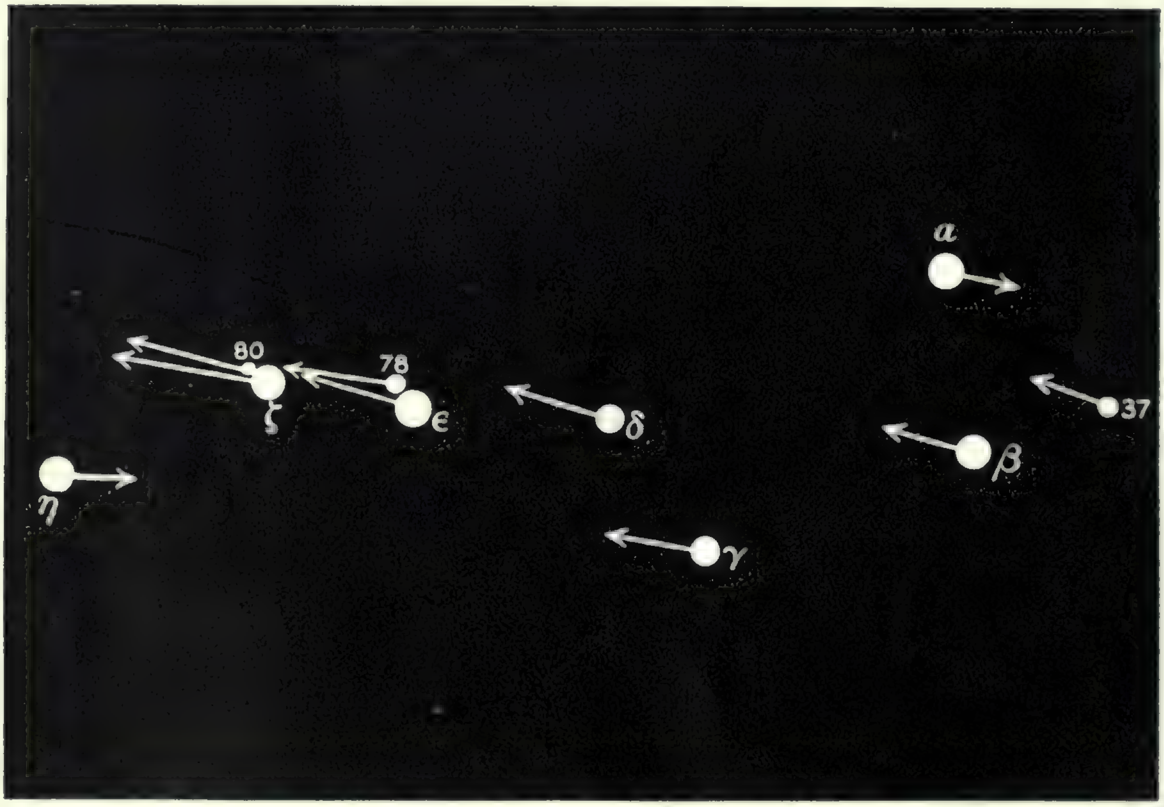
This is the type of instrument whereby the apparent positions of stars in the sky are determined with great precision. For this purpose it is provided with circles divided very accurately on silver or gold and the divisions are read by means of microscopes. Continuously repeated observations of the same stars year after year have provided data for calculating the proper motions of the brighter stars, but those of the fainter ones are now generally deduced from the measurement of photographs.

In considering the proper motions of the stars it must be remembered that our observations do not give the true direction or amount of the entire motion, but merely that part of it which appears as a change in position of the star in a plane at right angles to the line joining it and the observer. Of the component of motion in the "line of sight" nothing was known until the application of the spectroscope to the problem. By the displacements in the lines of the spectra of the stars, we are now able

to measure accurately the speed in miles per second with which a star appears to be approaching to or receding from us. As in the case of angular proper motions, the observed speed in the line of sight, or radial velocity, is that of the star and the component of solar motion in its direction.

From observations of radial velocities of stars in all parts of the sky, it has now been found that the Solar System is moving with reference to the system of the surrounding stars, with a speed of about 12·1 miles per second towards a point on the borders of the constellations Lyra and Hercules not far from the bright star Vega. This velocity will carry us about 382 million miles in a year, so that the stars near us at the present time are generally a different set from those previously occupying the solar neighbourhood, and in the future others will take their place.

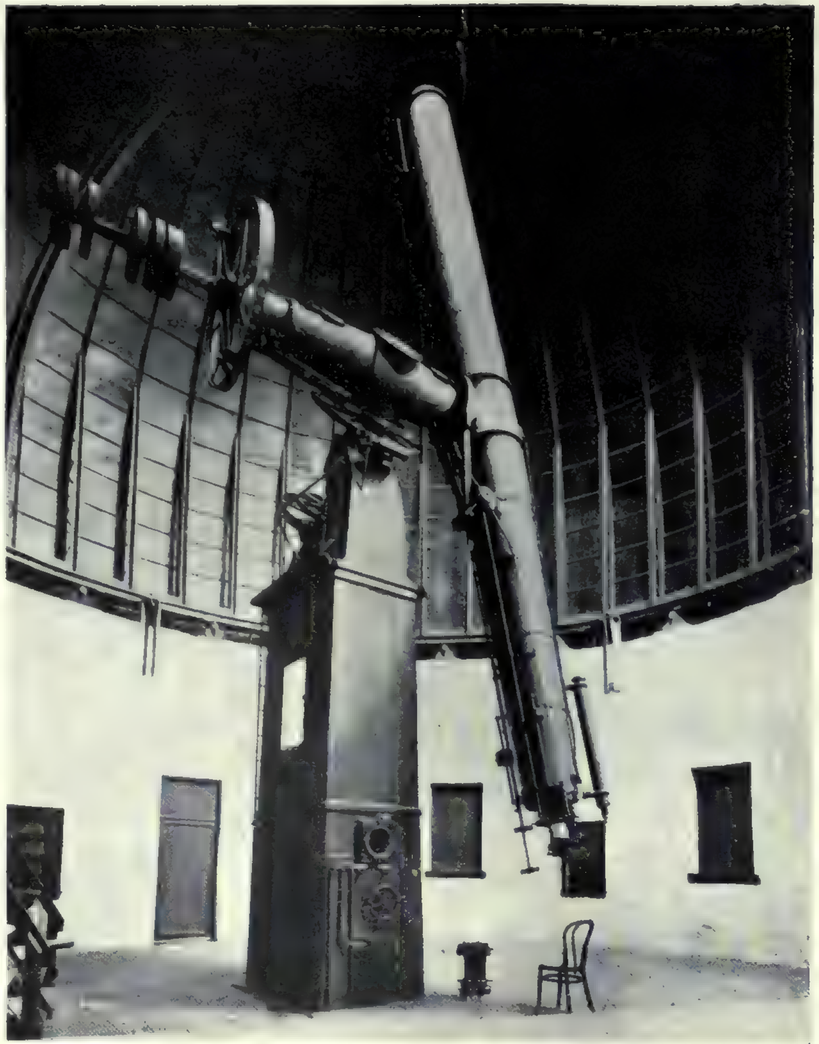
This motion provides us in the course of time with a much greater base line than the diameter of the



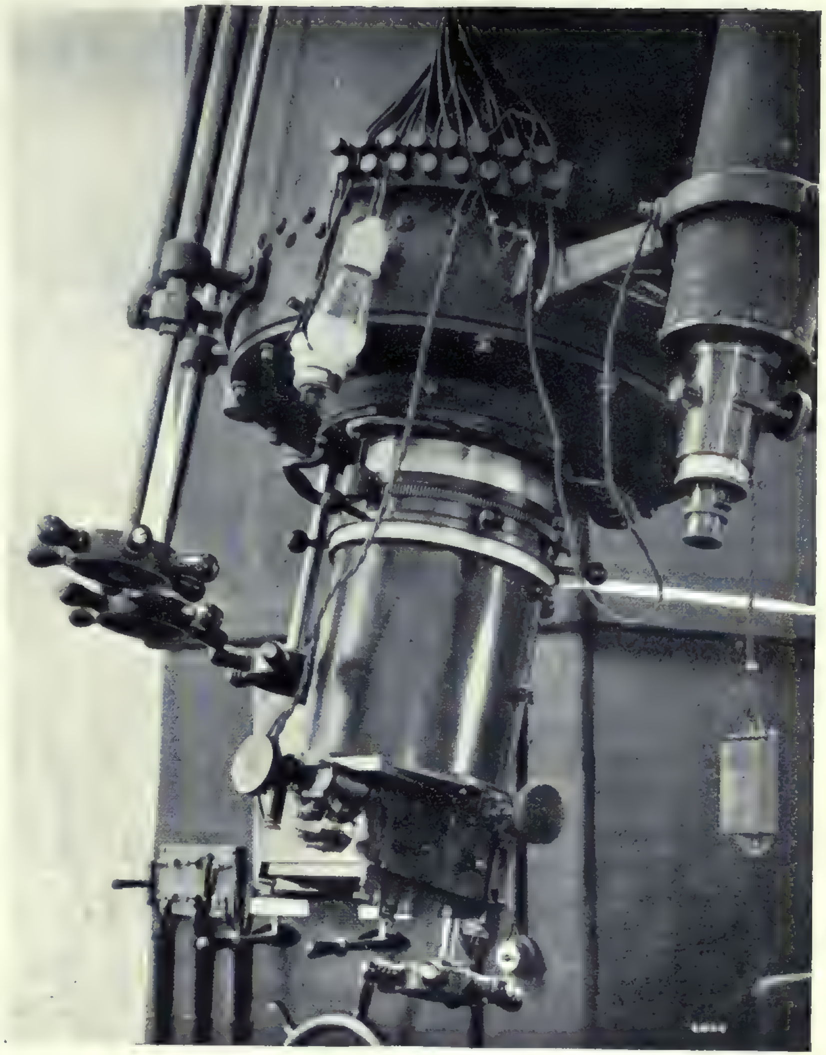
MOTIONS OF THE STARS IN THE PLOUGH.
This diagram shows on an exaggerated scale the motions in the sky of the Plough and neighbouring stars. All but Alpha and Eta are moving together through space, and are situated at a distance from the Earth which Light, moving at 186,300 miles per second would take about eighty years to traverse !

Earth's orbit, for the measurement of stellar distances. A star which would shift its position in the sky by only one-hundredth of a second of arc while the Earth in its orbit moved from one side to the other of the Sun, would show a shift of nearly two seconds, after the lapse of 100 years, from the motion of the Sun through space, and two seconds of arc is an angle which although very small, is much easier to measure than one-hundredth of a second. Similarly, the small proper motions of the stars which are too minute to be seen in a year's time become noticeable in a century, and the careful observations of several generations of astronomers have provided us with the changes in position from which are derived the motions of the stars across our line of vision which are termed their proper motions.

This new base line enables us to determine the average distances of groups of stars on the assumption that the different stars are moving in random directions and that therefore their individual motions



THE SPROUL TELESCOPE.



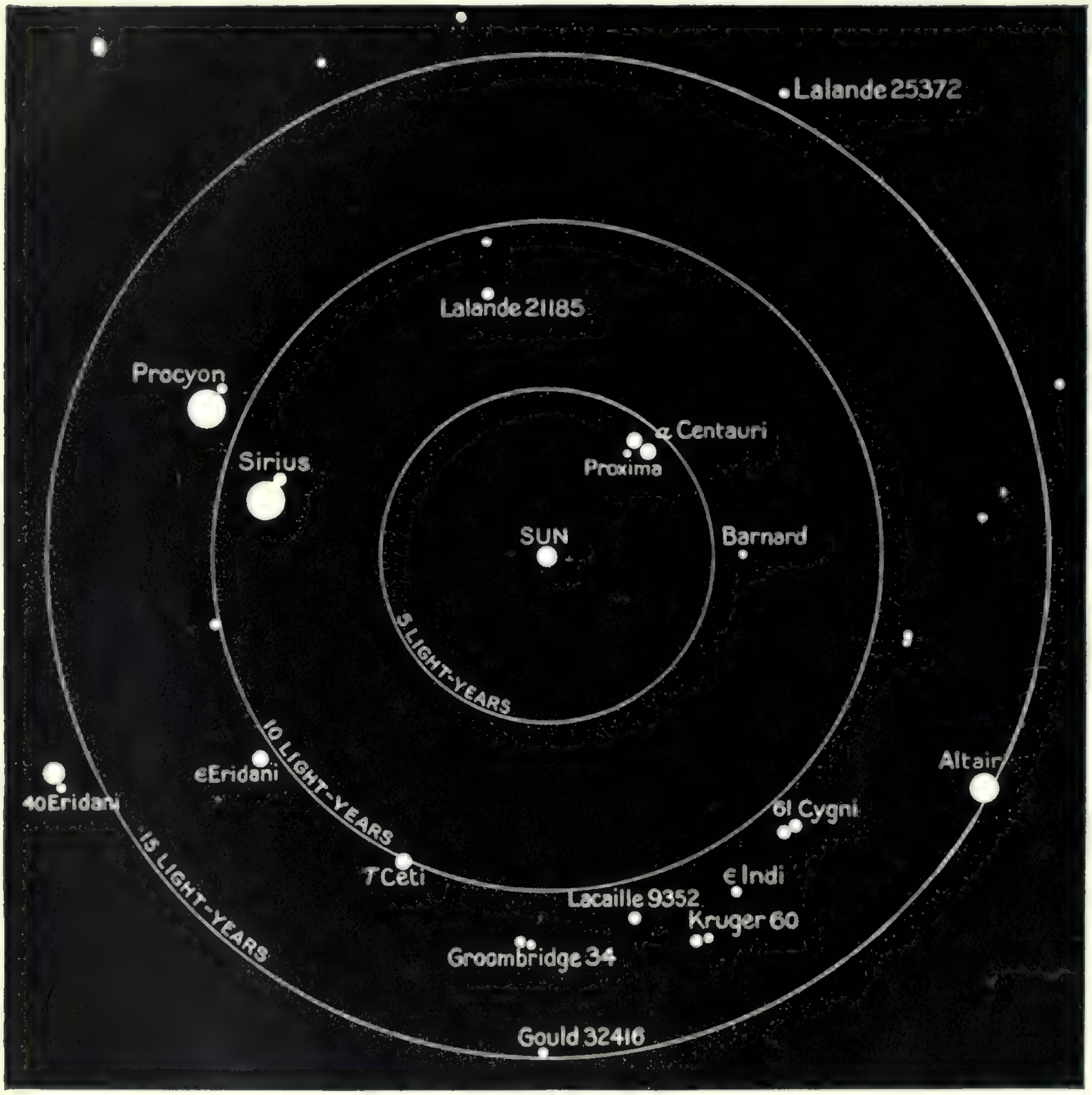
PLATEHOLDER OF SPROUL TELESCOPE.

From ["Popular Astronomy."

The above views are of the Sproul refracting telescope of twenty-four inches aperture and thirty-six feet focal length, which is chiefly used for taking photographs of stars at intervals of several months for the purpose of determining their distances. It is the gift of a wealthy American to Swarthmore College, Pennsylvania.

cancel each other in taking the average. From studies of this kind, we have been able to get reliable information regarding the distances of the great clusters and groups of stars and as a consequence to penetrate farther into space than by the direct measurement of individual parallaxes.

For example, we may find the average parallax of the stars of a particular grade of brightness by

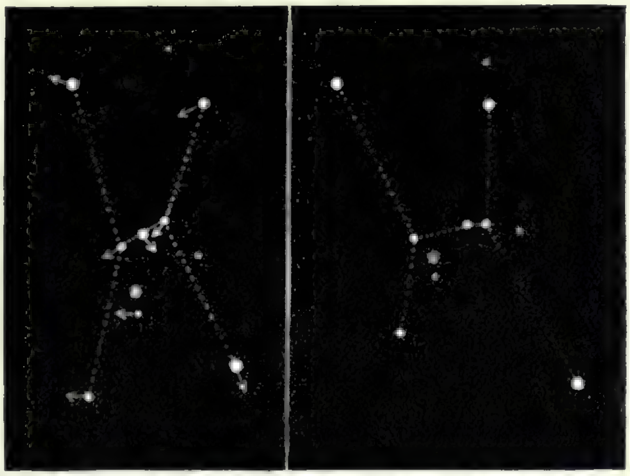


THE TWENTY-FIVE NEAREST STARS.

Our nearest twenty-five stellar neighbours (eight of which are double) are here shown at their relative distances. Their total brightnesses vary from twenty-eight times (Sirius) to about a seventeen-thousandth (Proxima) of the Sun. The relative sizes of the stars are approximately as shown but are exaggerated enormously in comparison with their distances apart.

the use of this base line. As is described in another chapter, the stars are graded in stellar magnitudes, those visible to the naked eye being included in the first six magnitudes or so.

Taking each class and dealing with that part of their proper motions which is a reflex of the translation of the Solar System through space, averages as follow have been determined. It should be borne in mind that there is a great diversity of brightness in the stars, and that consequently those which are



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ORION TO-DAY AND AGES HENCE.

The proper motions of its individual stars will, in the course of many thousands of years, completely distort the whole constellation and render it utterly unlike the familiar form we know to-day.

classed together in a particular grade of apparent brightness are really at extremely varying distances. The figures given are therefore only rough averages. Meanwhile it will be as well to note that (as will be described in the chapter on Giant and Dwarf Suns) the redder stars have a much greater diversity of brightness and distance for a given apparent magnitude than the whiter ones.

First magnitude		...	80	light-years.
Second	,,	...	100	,,
Third	,,	...	135	,,
Fourth	,,	...	170	,,
Fifth	,,	...	215	,,
Sixth	,,	...	280	,,

There is another method by which the measured proper motions and radial velocities are utilised to give average distances of groups of stars. Perhaps a simple illustration will help us in making clear the means by which this is done. The reader may imagine himself at sea and that all round are a number of very distant boats moving at random in all directions. With a telescope the motions can be studied and tabulated so that we could say, for example, that the boats were moving on an average perhaps ten degrees of arc per hour across the field of view. This by itself would not tell us anything about the distance of the boats.

If, however, we knew that the actual rate of movement across our field of view were on the average five miles per hour, some moving faster and some slower, then the problem would be to find how far away an object must be so that a base line of five miles must look like ten degrees. The answer would be that the boats must be, on the average, about twenty-eight miles from us. Some might be much closer and others much farther away, but if their average movement across the field of our telescope were ten degrees per hour and we were able to find that their average actual movement was five miles in an hour, we should be able to ascertain their average distance as given above.

In the case of the stars the problem is more complicated than in the simple illustration, as the observer is in motion due to the translation of the Solar System. The value of the Sun's own motion through space must therefore be eliminated from the observed radial velocities of the stars and that part only of the proper motions used which is not affected by the journey of the Sun through space.

The measurement of the distances of clusters of stars such as those mentioned in an earlier paragraph is made by a variation of this method. In the case of the Taurus Moving Cluster, which consists of a number of stars of about the fourth magnitude and fainter situated mainly in the constellation Taurus with the Hyades cluster nearly at its centre, common proper motions have been known for some time. When these motions are shown graphically a striking feature presents itself. They are all apparently converging to a point in the sky about five degrees east of

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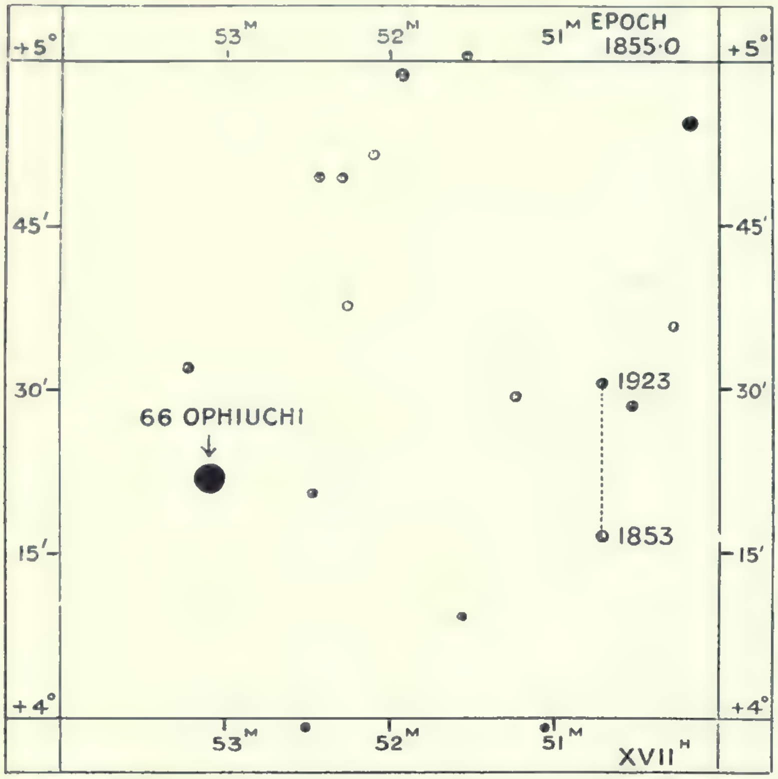
CHANGES IN THE PLOUGH IN 200,000 YEARS.

The middle picture shows the Plough as it appears to us to-day, the arrows indicating the directions in which the individual stars are moving. The motions are too slight to make any obvious change in the shape of the group in a short time, but the upper and lower pictures show the effect of the movement 100,000 years hence and 100,000 years ago respectively.



Drawing by] [*W. H. Steavenson.*

A RUNAWAY STAR.

An insignificant star in Ophiuchus, between the ninth and tenth magnitude, was shown by Barnard in 1916 to have the largest proper motion yet known. This motion amounts to 10·3 seconds of arc per year, enough to displace the star a Moon's breadth in about 190 years. The chart above will enable any observer to find the star (with a small telescope) after identifying the star 66 Ophiuchi on a star chart. The motion in seventy years is indicated by a dotted line.

the bright red star Betelgeuse.

An exactly similar converging motion is observed in the case of the apparent paths of a flock of birds or squadron of aeroplanes which are flying across our line of sight and at the same time receding from us. Now the receding radial velocities have been spectroscopically measured for a number of the stars concerned, and consequently we can calculate the true paths of the stars of the cluster in space assuming that they are really parallel and that their convergence is only apparent and due to their recession from us. We can then compute the distance of the cluster as about 130 light-years and also its dimensions assuming the shape to be roughly spherical. The diameter would appear to be about fifty light-years or nearly twelve times the distance separating the Sun and the nearest star. Independent measures of parallax of some of the stars by various methods corroborate these values. By this and other methods referred to later, the distances for well-known clusters and groups of stars have been found as below :—

Cluster or Group.	*Approximate Distance, Light-Years.*
Stars in the Plough	80
Stars in Taurus Group (including Hyades)	130
Stars in constellation Coma Berenices	290
Moving Group in Perseus	350
The Pleiades	350
The Beehive (Praesepe)	400
Stars in constellation Orion	600

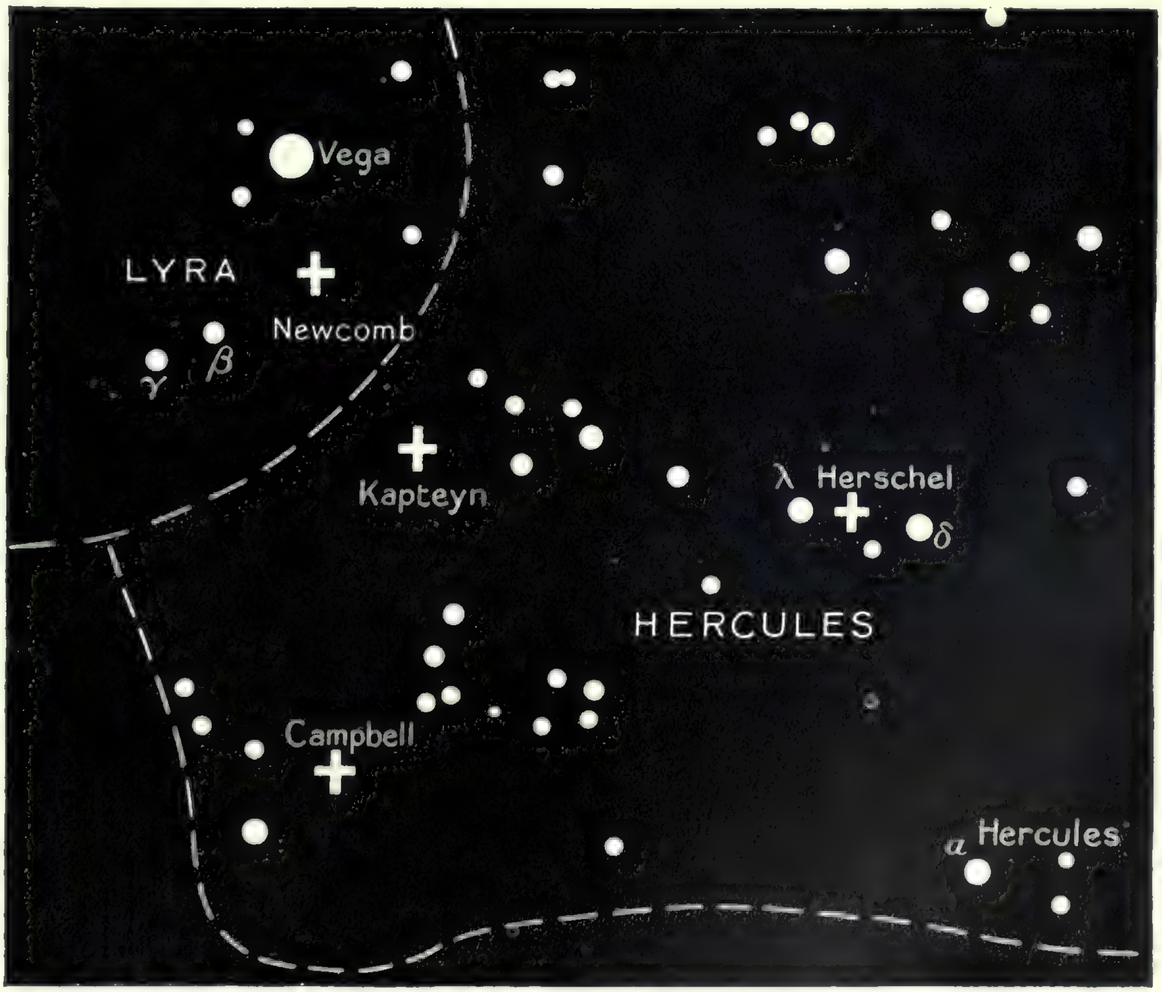
As in the case of the problem of measuring the Sun's distance, there are some indirect ways of getting at the distances of the stars in addition to those based on the apparent shift of the stars in the sky caused by motion of the Earth in its orbit, of the Solar System in its translation through space, or of the stars themselves. There is, for instance, the method based on photometry or light measurement.

It is an everyday experience that the brilliancy with which lights appear to us, a row of street lamps for example, depends upon the actual brightness of the lamp (its candle-power) and upon its distance from us. Similarly, a star's apparent brightness is dependent upon these two factors of real luminosity

and distance. Since the apparent intensity of a light varies inversely as the square of its remoteness from us (twice as far meaning one-quarter the light, and so on) it would be a simple matter to determine the distance of a star if we knew both its actual and its apparent output of light.

For the purpose of expressing the difference in apparent brilliancy of the stars, astronomers have adopted a scale, the unit of which is called the magnitude, each magnitude differing from the next higher or lower on the scale in the ratio of 2·512 to 1. This number appears rather an awkward one to use but has certain advantages mathematically and is founded on an adopted ratio of 100 between the lights of an average first magnitude star and one five magnitudes fainter. In order that a star will shine one magnitude fainter it would require to be put at 1·585 times its previous distance, this number being the square root of 2·512. Or, inversely, a star brought nearer so that it shone one magnitude brighter, would be at about sixty-three per cent. of its former distance.

These relationships assume that there is an unobstructed passage of light through space. For example, if a row of street lamps is observed through a mist or fog, those farthest from the eye are dimmed to a greater extent than those nearer at hand, and we might consider them to be more remote



APEX OF THE SUN'S WAY.
The Sun and its attendant train of planets are moving through space at about twelve miles per second. The direction of this movement has been computed from the motions of the stars on the sky. On the one side of the sky those stars to which we are approaching appear to open out; on the opposite side those we are leaving appear to close up, just as trees appear to do to a man moving through a forest. The crosses show the point to which the movement is directed, according to various astronomers.

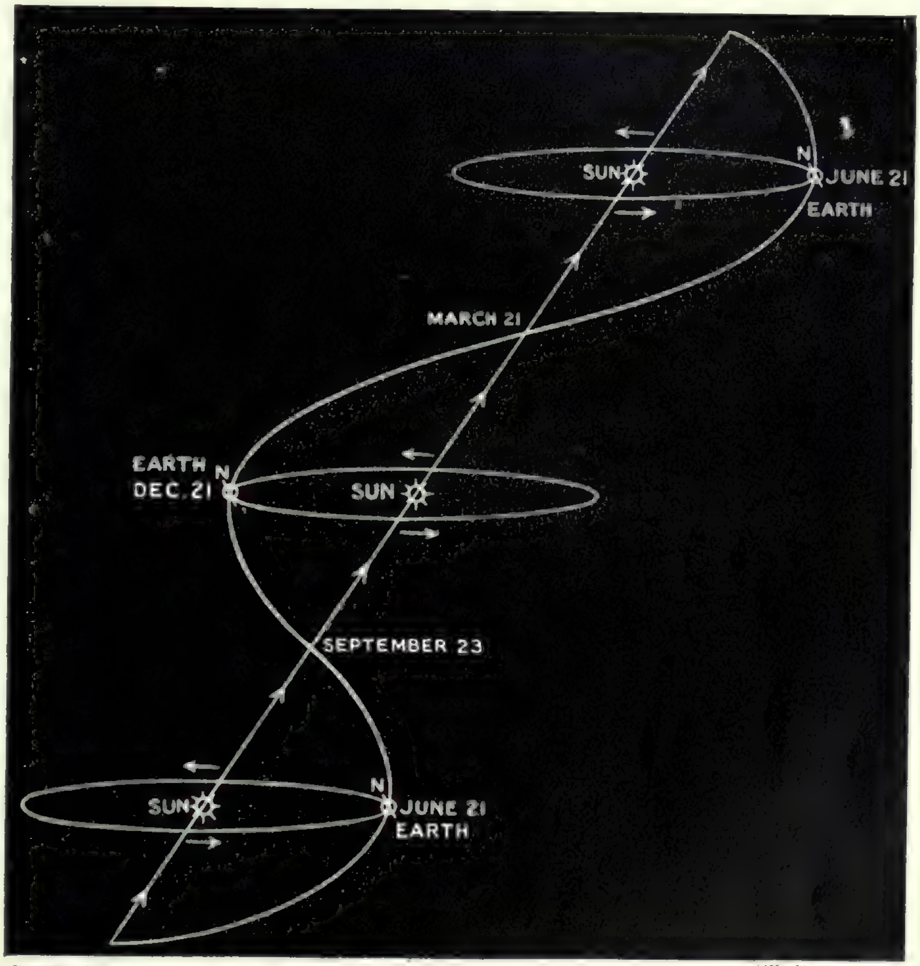
CHART OF HEMISPHERE OF SKY FROM WHICH THE SUN IS RECEDING.

CHART OF HEMISPHERE OF SKY TOWARDS WHICH THE SUN IS MOVING.

Distribution of to and fro motions in two hemispheres. The motions in the line of sight of nearly 1,000 stars are shown in the two circles above. The dots are the stars which have a movement towards the Solar System; the crosses are those which have a movement of recession. The motion of translation of the Sun through space is thus well brought out.

than they really are if we made no allowance for the absorption of light. For some time astronomers were of the opinion that there was evidence of a diminution of stellar light in its transit through space by the action of some sort of celestial fog or through want of perfect elasticity in the æther, but the most recent research would indicate that the loss, if any, is quite inappreciable, except in parts of the sky where certain obscuring clouds are to be found.

Until quite recently it was not possible, however, to estimate the parallax of a star by photometric methods. There was no means whereby stars could be graded in regard to their true luminosities, all that could be said being that their light outputs varied very greatly from one star to another. In the next two chapters, "The Message of Starlight" and "Giant and Dwarf Suns," a description will be given of the modern discovery which enables us to make fairly close estimates of the real luminosity of any star of a particular colour or type of spectrum, and from this development in knowledge, it is now possible to obtain an idea of distance of stars and objects in cases where the remoteness is far beyond the possibilities of direct parallax work. Parallaxes found by this method are referred to as "spectral parallaxes" depending as they do on the identification of the spectral types of the stars concerned. In the case of stars which are too faint for determination of their spectral type, we are able to determine their colours by the use of coloured screens superposed over specially sensitised photographic plates. These colour values can also be related with some precision to luminosity of the stars concerned and information as to distances be thereby obtained.

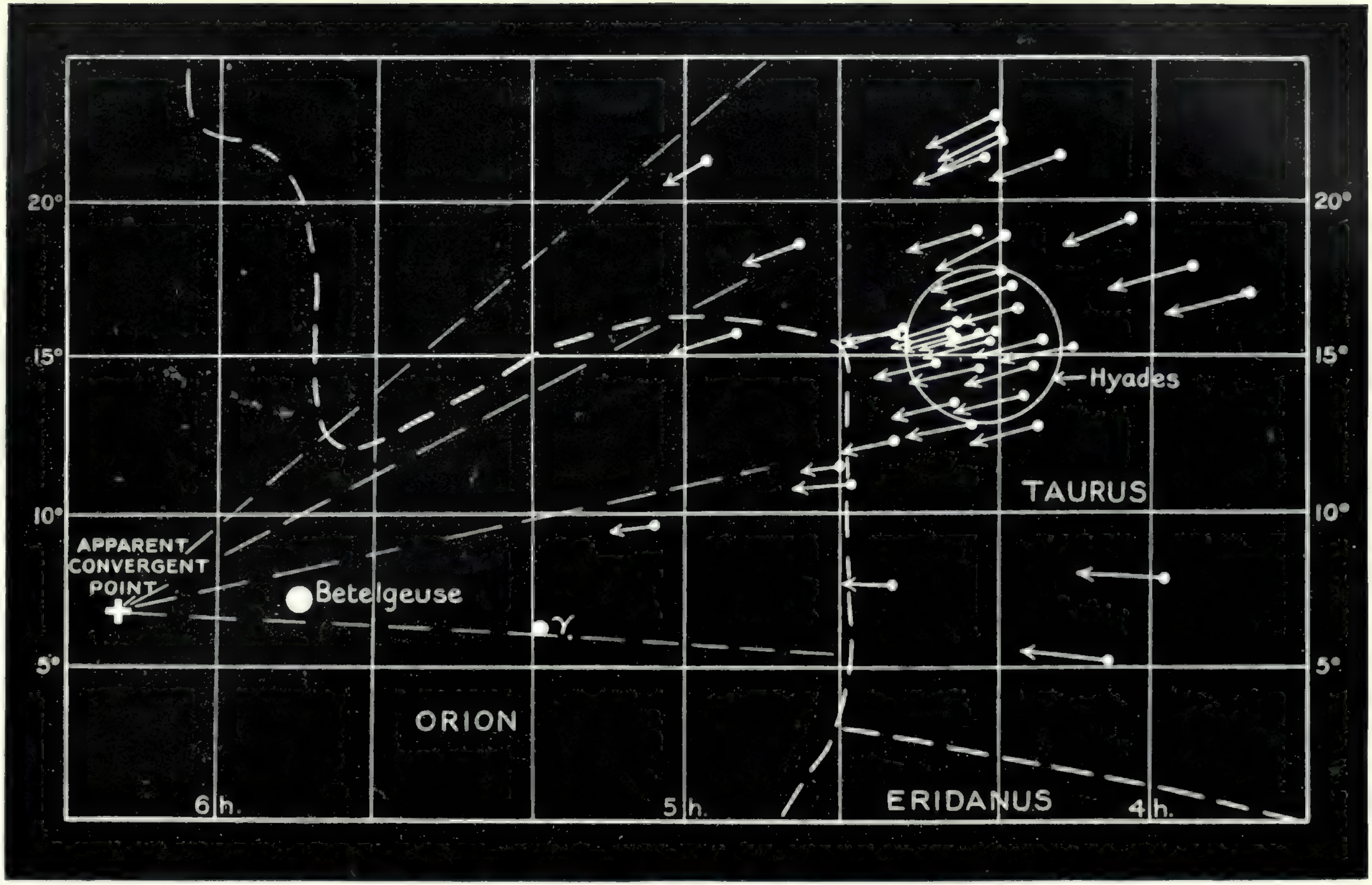


Drawing by] [*W. H. Steavenson.*

THE EARTH'S PATH IN SPACE.

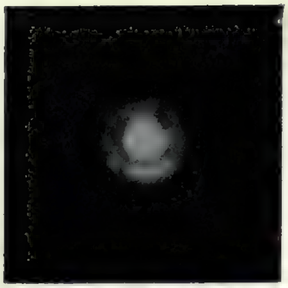
The result of its orbital motion, combined with the bodily translation of the Sun and the whole Solar System, is that the Earth's path in space, relative to the visible heavens as a whole, is in the nature of a helix, or corkscrew. The considerable extent of the solar motion in a single year is shown to scale on the above diagram, and it will readily be seen that it must provide a very respectable base-line for parallax determinations after the lapse of a number of years.

Another indirect method of the greatest value and importance is that devised by the American astronomer W. S. Adams, of Mount Wilson, California. From an examination of the spectra of stars



TAURUS MOVING CLUSTER.

About forty stars are known to have apparent converging movements towards a point east of the bright red star Betelgeuse. By these movements and the velocity in the line of sight measured by the spectroscope, the distance of the group has been found to be such that light takes 130 years to travel from these stars to us.



A "PLANETARY" NEBULA.
This type of nebula consists of a shell or globe of gas, generally with a star-like nucleus at the centre. The presence of this nucleus affords for measurement a well-defined point, such as is lacking in most other types of nebula. Hence it has been possible to measure the parallaxes of several "planetaries." The distance of the one above is found to be about 160 light-years.

of known distances it has been found that the intensities of certain of the lines in their spectra vary with the true luminosity of the star. If these lines are studied in the spectra of stars for which the distance is required, the real light output can be closely estimated, and this, in conjunction with the star's apparent brightness, at once furnishes the data for computing the distance. We have here a method which, although depending fundamentally on direct parallax determinations for its scale, enables us to get knowledge of distance. It is not limited, as in the case of direct parallax determination, by the length of a base line, but is applicable to stars, however distant, providing they are bright enough to permit of photographing their spectra on a sufficiently extended scale, and obviously the limit here is size of telescope which is much more easily got over than inadequacy of base line. Over 2,000 stars have been dealt with in this way, the values got having been given the designation "spectroscopic parallax."

An approximate parallax for a binary star, in which relative movement of the two components has been observed, can be calculated from a law connecting the masses of such systems with their times of revolution and the distances apart of the constituent bodies. The period of revolution being known, the masses are assumed to be comparable with that of the Sun, or of similar binaries for which the distances have been measured and the masses calculated, and the linear distance between the components can then be computed. The angular separation of the stars is measured and knowing the linear dimension to which this angle corresponds, the parallax is derived. As the value thus obtained depends on an assumed mass, it is only approximate and is termed a "hypothetical" or "dynamical" parallax.

Another class of stars for which parallaxes can be indirectly derived are the variable eclipsing binary systems. For these objects, which will be described in the chapter on Variable Stars, the diameters of the two stars can be calculated from the shape of the curve of light variation. The intensity of surface brightness, or light emitted per unit of surface area in comparison with the Sun, can be estimated when the spectral type has been

Photo by] [*Judges' Ltd.*

DISTANCE AND LUMINOSITY

The apparent luminosity of a source of light varies inversely as the square of its distance from the observer. Applying this rule we can estimate the distance of a star (or lamp) if we know its real brightness; or, conversely, we can deduce the latter if we know the distance. Both applications of the law are in use by astronomers in the determination of the distances and "absolute magnitudes" of the stars.

Photo by] [*Isaac Roberts.*

THE GREAT CLUSTERS IN PERSEUS.

These two objects, which are together visible to the naked eye as a misty patch, are among the finest examples of the "open" type of stellar clusters. Like most others of their class they are situated in the course of the Milky Way, and are characterised, as distinct from the "globulars," by the great brightness of their component stars, which are also more loosely and irregularly distributed.

ascertained. From the calculated diameters the areas of surface are computed and these in conjunction with the intrinsic surface brightnesses give the total light output in terms of the Sun's. The apparent brightness being known, we then have the necessary information for deriving a hypothetical parallax. In this way, estimates of the distances of nearly two hundred eclipsing pairs of stars have been secured, most of which are too remote for direct parallax measurement.

The indirect methods are used in estimating the remoteness of such objects as the obscuring clouds, globular clusters, and the Milky Way clouds of stars. In the case of the obscuring clouds the task of measuring the distance of such indefinite and amorphous masses might appear beyond our powers. However, the very circumstance by which the existence of these clouds is revealed provides a means, namely, the deficiency of stars in the sky. In the case of one which covers about seventy square degrees of the northern part of Taurus, counts of the stars have been made which show a marked drop in the number per square degree inside its confines. The stellar density is found to be only one-fifth of what it is in the immediately surrounding parts of the sky, and the reduction in the brightness of the stars can be calculated from this deficiency in numbers, and also the distance of the stars on the nearer side which are not affected. These calculations indicate a distance of about 500 light-years. There are some stars involved which are abnormally red in comparison with others elsewhere of the same spectral type, and this is supposed to be the effect of the cloud, which, like fog, is thought to be likely to redden stars seen through it. The minute directly measured parallaxes of these stars agree as well as could be expected with the distance derived from the counts of stars.

Another obscuring mass of great interest is situated on the borders of the constellations Ophiuchus and Scorpius. Here the parallax has been estimated from the deficiency in numbers of a particular type of star, the hot white B type. These are relatively scarce in this region for the grades fainter than

about the sixth magnitude. Now this type of star is one for which the real luminosity is fairly constant from one star to another and the value is well known. Assuming that the relative absence is due to the screening effect of the cloud, the distance is calculated to be approximately 800 light-years.

The distances of the luminous nebulæ have been found in some cases by studies of the stars with which they are connected. For example, in the case of the great nebula in Orion, the stars in that constellation are believed from their proper motions and luminosities to be about 600 light-years away, and the nebula is obviously connected with many of them. Certain forms of nebulæ, known as the planetary type from their planet-like disc shape, have central stars which can be made the subject of direct parallax measurements with powerful photographic telescopes. They can also be measured for proper motion, and an idea of their average parallax then obtained. Certain of the larger ones are situated at distances of from about 80 to several hundred light-years, while the average for over

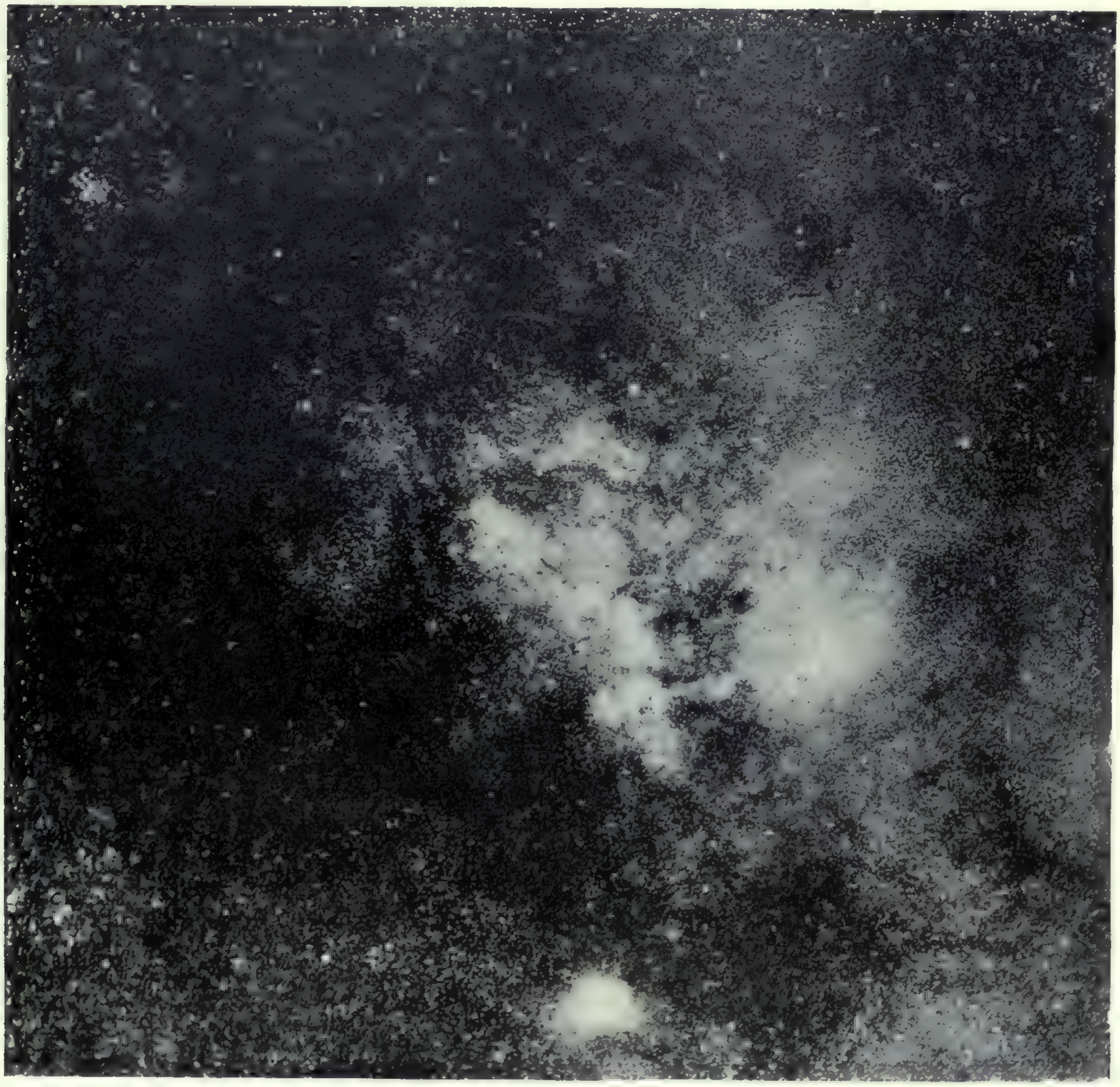


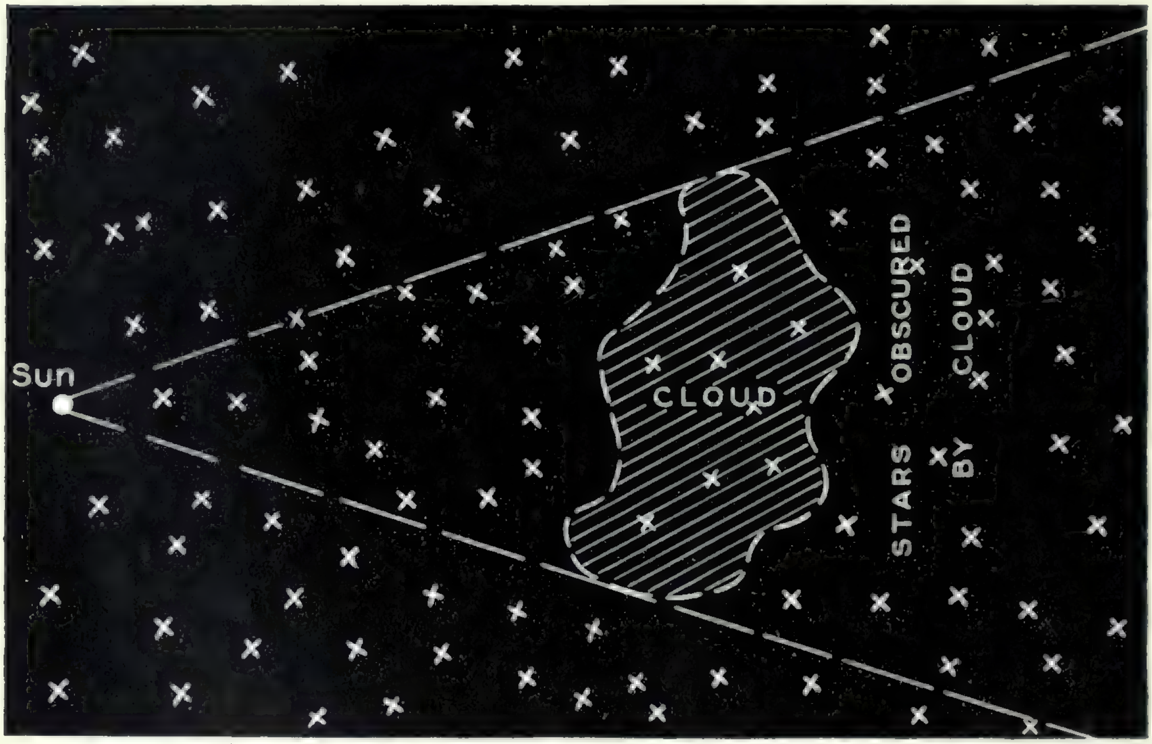
Photo by] [*E. E. Barnard.*

THE GREAT STAR CLOUD IN SAGITTARIUS.

This great mass of stars forms one of the brightest sections of the Milky Way. The close aggregation of the stars is in part only apparent, being due largely to their great distance and to the fact that we are looking through a stratum of considerable depth. A recent estimate of the distance of this star cloud is 200,000 light-years. Other portions of the Milky Way are still more remote, perhaps as far as 400,000 light-years.

seventy whose motions are known is about a thousand light-years as found by the method of proper motions and radial velocities described in a preceding paragraph.

With regard to the problem of the distances of star clusters, so remote that even the lapse of a long period of time does not show any apparent change of position in the sky, this is attacked by various indirect methods which are mainly based on photometric studies of the included stars. There are two general types of star cluster: the open or loose type, and the globular cluster. The former are all near the plane of the Milky Way, and are situated at very varying distances from us which are not known with any degree of precision except for such nearer objects as the Pleiades or Hyades. The estimation of the parallaxes of globular clusters cannot be based on the direct geometrical methods ; the order of remoteness is far too great for this. By comparison of the magnitudes of the brightest stars in them with those of the same spectral type or colour in the neighbourhood of the Solar System, distances

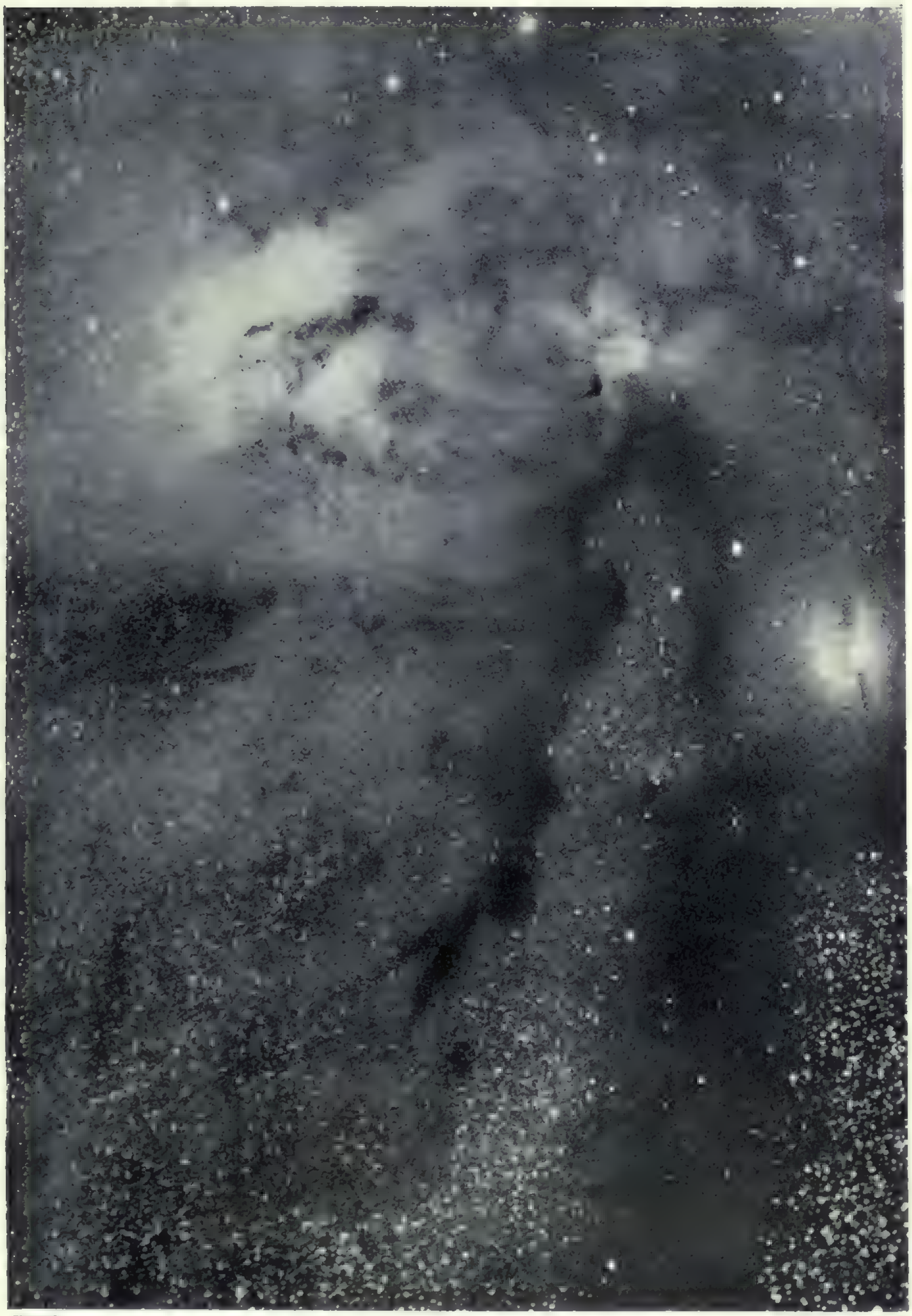


ESTIMATING THE DISTANCE OF AN OBSCURING CLOUD.
Many dark markings on the sky, due to clouds of dust and gas which absorb the light of the stars beyond them, are known. The distances of several have been estimated from their effect in reducing the number of stars visible as compared with those in surrounding parts of the sky.

have been derived by modern workers. Another method used is founded on a remarkable law connecting the luminosities of a particular type of variable star (the Cepheid), common in the globular clusters, with their periods of variation, which will be described in the chapter on Variable Stars. From the distances thus derived a similarity in the actual diameters of the globular clusters has been found. The remoteness is thus directly proportional to the apparent angular diameter of the cluster and this can be applied to finding the parallaxes for the smaller and fainter objects of the class whose individual stars have not yet been studied. The distances obtained from these methods by the American astronomer Dr. Harlow Shapley, of Harvard College Observatory, are exceedingly great, and much in excess of what has been believed since the time of Sir William Herschel, who also favoured very great remoteness for these objects, although, perhaps, on inadequate observational material. Shapley's distances, which are now generally thought to be of the correct order of magnitude, vary from about

21,000 light-years in the case of the nearest (Omega Centauri) to about 220,000 light-years for the most remote.

To observers in the southern hemisphere, there are visible to the naked eye two nebulous spots of light, not unlike portions of the Milky Way although appearing some distance in the sky from the galactic circle, known as the Magellanic Clouds or Nubeculæ. From the known luminosities of some of the stars in them, particularly the bright white stars and the Cepheid variables, and also from the angular diameters of some globular clusters situated in the greater Cloud, the distance and diameter have been estimated at 115,000 and 15,000 light-years respectively for the larger, and 65,000 and 5,000 light-years for the smaller Cloud. These objects are possibly universes separate from the main stellar system and contain stars, clusters and nebulæ of varied types.



From] [*"Knowledge."*

DARK CLOUDS NEAR RHO OPHIUCHI.

The distance of these markings, and of the luminous nebulae which are probably connected with them, has been estimated by several astronomers. From their obscuring or screening action there is a relative deficiency of the hot white B type stars, the distances of which are approximately known. By this criterion Dr. Shapley of Harvard College Observatory has derived a distance for the clouds of between 650 and 1,000 light-years.

The distances and constitution of the spiral nebulæ are matters which are as yet the subject of considerable controversy. Some astronomers consider these bodies to

be separate universes of stars, basing this conclusion largely on their spectra, which resemble that of a star or of a compressed cluster of stars, and also on the appearance of temporary stars in them, which if of the same order of luminosity as those appearing elsewhere in the sky would indicate distances of millions of light-years. Other astronomers, however, believe them to be composed of dust and gas shining by reflection from the stars included in them, the distances being comparable with those of the globular clusters. Van Maanen has lately shown that motion of the various portions of certain spirals can be detected after an interval of only a few years, and, if the actual velocities are of the order of those observed elsewhere in the heavens, motion could hardly be manifested in so short a time at distances greater than a few thousand light-years. The final solution of the problem of their distances is for the future, but the present trend seems towards the smaller values.

EDMUND HALLEY (1656-1742).
Second Astronomer Royal (1719-1742) and a contemporary and friend of Newton. He discovered the periodicity of the comet bearing his own name and the proper motions of several of the "fixed" stars. He also devised a method of measuring the Sun's distance by observation of Transits of Venus across the solar disc. One of his greatest services to science consisted in persuading Newton to publish his immortal gravitational discoveries.

The distance of the confines of our universe of stars has been estimated by various astronomers by methods based chiefly on the luminosities of stars. Assuming that the faintest stars photographed in the Milky Way are comparable in real output of light with the brightest orbs in the neighbourhood of the Sun, the farthest limits must be tens of thousands of light-years distant. Dr. Shapley has shown that the globular clusters are evidently part of our universe and that the Milky Way seems to be co-extensive with the system of these clusters. If so, the diameter of the stellar system is probably something like 300,000 light-years. The consideration of this, however, belongs more properly to the question of the Structure of the Universe, which will be dealt with in a later chapter. One remarkable feature of the sky as it presents itself to us is worthy of reference. With the naked eye on any clear night, we are looking at the inhabitants of space, *not* as they exist at the moment of observation, but as they existed at various past times up to about 2,000 or so years ago! This is because the individual stars visible to unaided vision are at distances ranging up to something like 2,000 light-years. With the aid of even a small telescope the range in past time is certainly tens of thousands of years—it may indeed be millions!

CHAPTER XII.

THE MESSAGE OF STARLIGHT.

By Herbert Dingle, B.Sc., F.R.A.S.

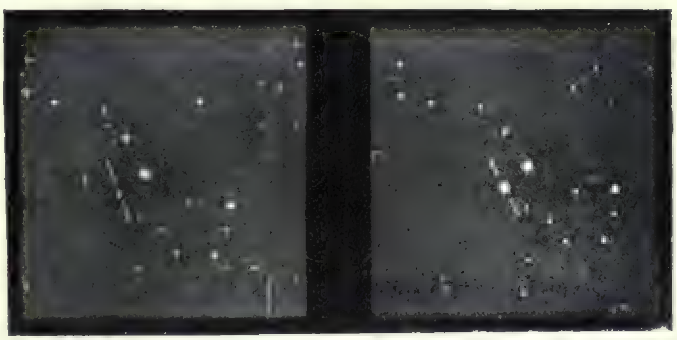
It is remarkable that the stars and planets, though to the eye they appear almost indistinguishable, have actually scarcely a feature in common. If one runs in mind through the various characteristics of the heavenly bodies in which the astronomer is interested—size, mass, movements, temperature, brightness, and the rest—the differences, without exception, are almost as great as it is possible to conceive. To the ancients, of course, these differences were unknown. In calling a few of the heavenly bodies "planets"—that is, "wandering stars"—they called attention to the one clear point of distinction which they could establish between those bodies and the stars—their movements were different. It had to be left to modern times—and, in the main, to the second half of the last century—to show how radically distinct were the two types of body.

Photo by] [*Cambridge Observatory.*

FOUR-PRISM SPECTROGRAPH OF NEWALL TELESCOPE.

The Newall Telescope, when it was erected, was the largest refracting telescope in the world. It is now at the Solar Physics Observatory at Cambridge.

For a time, indeed, it seemed as though the chief effect of the advance of knowledge, so far as the stars were concerned, was to emphasise our ignorance. In very early times, the relative distances of the brighter planets were known, but not those of the stars. To the early astronomers the stars were all at the same distance—how great, none could measure—embedded in a crystalline sphere which revolved with absolute precision once a day round the Earth. Later, during the Renaissance period, when the form and laws of working of the Solar System were discovered, the stars still preserved their mystery. The labours of Tycho Brahé and Kepler, the telescopic observations of Galileo, and even the genius of Newton, alike failed to throw the faintest light on the problem of the stars. The great forward movement in astronomical thought which took place at that time not only told us nothing about them; it took away even the little which we thought we knew before. It showed that the diurnal movement of the stars was not a real movement at all, but an illusion arising from the daily rotation of the Earth on its axis; it was not the stars that moved, but we ourselves. The telescope, which had revealed so much in our own Solar System, could do nothing with the stars. It showed them still as points of light—brighter, it is true, and increased in number, but without the slightest hint of magnification. There was no perceptible change of position of the stars as the



From] [*"Astrophysical Journal."*

PHOTOGRAPHS ILLUSTRATING COLOUR-INDEX OF A STAR.

Stars whose images appear of the same size on the two plates are bluish-white stars. The star (μ-Cygni) which appears much larger on the right-hand plate is a red star.

Earth moved across many millions of miles in its orbit—an indication that the stars were exceedingly distant, but entirely devoid of anything more definite. We were left with a sky peopled by unnumbered, immovable, unmeasured points—a series of negatives with no apparent sign of a positive.

And yet all the time there was a positive, so obvious as to be overlooked, and yet so exceedingly significant that we can see no limit to the knowledge that it is able to bring to us. We might have added the word "luminous" to our list of adjectives, and by so doing have taken the whole sting out of the array of negations. For, in the fact that a star emits light lies the possibility of the latest and most extensive branch of Astronomy—Astrophysics. The planets also send light to us, but not their own light. They reflect the light of the Sun, and so, in the most important characteristic of all, we see that they and the stars are unlike one another. We can study the planets because light shines on them; we can study the stars because their light shines on us.

The message of starlight is delivered in three more or less distinct ways. It is embodied, first of all, in the total amount of light we receive from a star, or (a closely related quantity) the total amount of light which the star sends out in a given time. Secondly, there is a message in the colour of that light. Stars, as we know, differ greatly in colour, from the red glare of Antares or Betelgeuse to the clear bluish-white glow of Rigel or Regulus. Finally, and most striking of all, there is the structure, or spectrum, of the light. We must consider briefly how these three characteristics of starlight have opened up a new heaven to the watchers of the skies.

The principles and methods concerned in measuring the apparent brightness of the stars will be fully discussed in a later chapter. It will be sufficient here to say that astronomers have adopted a regular classification of the stars according to their brightness, as seen from the Earth. The divisions of this classification are termed "magnitudes," and each of these is numbered according to its order in the scale. Thus the brightest stars are said to be of the "first" magnitude, while the faintest visible to the naked eye are classed as of the "sixth." Stars of any one magnitude bear a definite relation to those of the next below, being almost exactly two and a half times as bright. This rule is extended to the telescopic stars, where magnitudes even as low as the twenty-first are within the range of powerful instruments.

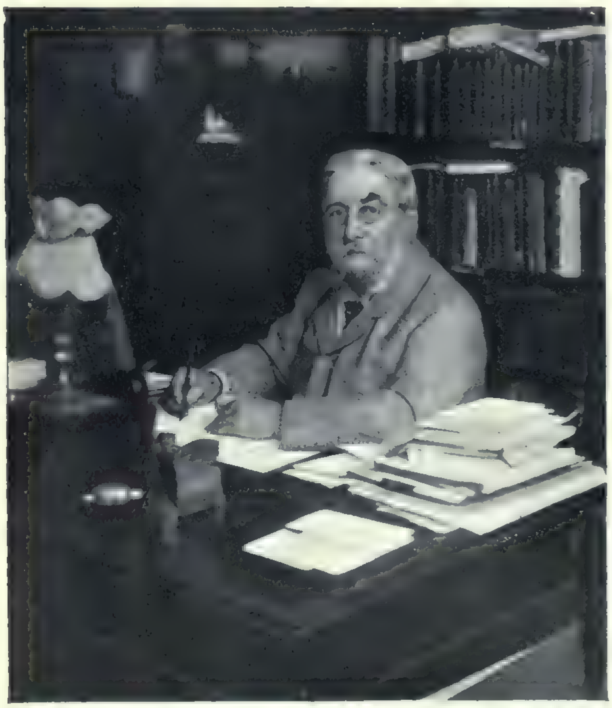


Photo by, Messrs. Russell & Son.

SIR JOSEPH NORMAN LOCKYER, K.C.B., F.R.S.

Sir Norman Lockyer was one of the pioneers of Astrophysics, and was the originator of the modern view that stellar spectra are determined mainly by temperature. His work covered the whole field of Astronomy. He was the founder and editor for fifty years of the scientific journal, "Nature."

There is no fundamental difficulty in measuring the apparent magnitude of every star that can be photographed; the one thing necessary is time. Unfortunately, that is not true of the real brightnesses of the stars. A knowledge of the real brightnesses of the stars involves a knowledge of the distances, and this, unfortunately, we possess for comparatively only a very few stars. It is known that, if a source of light be placed at varying distances from the eye, its apparent brightness will vary as the inverse square of the distance. For example, if a star has a certain apparent brightness at a certain distance, it will appear only one-quarter as bright if it is removed to twice the distance. Suppose, then, that we know the distances of a number of stars, and have measured the

apparent brightnesses. We can then calculate relatively how bright the stars would appear if they were all brought to the same distance from the eye, and it is clear that their apparent brightnesses in that event would represent their real brightnesses, for the effect of varying distance would be eliminated. A standard distance of ten parsecs (parallax 0·1 second of arc corresponding to a distance of 190 million million miles) has been chosen, and the apparent magnitude which a star would have at that distance is called its *absolute* magnitude. It is clear that in the absolute magnitude of a star we have some information about the character of the star itself.

Photo by [*Lafayette.*

PROFESSOR ALFRED FOWLER, F.R.S.

Professor Fowler, of the Imperial College, South Kensington, is one of the greatest of living authorities on Spectroscopy as an independent science and as a branch of Astronomy. He has made many contributions to the interpretation of stellar spectra, and to the study of atomic physics.

It appears that the absolute magnitudes of stars vary over almost as wide a range as their apparent magnitudes. There are stars 10,000 times as bright as the Sun, and others which, even at the standard distance, are too faint to be detected by virtue of their light. This is exceedingly important, for it assures us that, whether or not the stars were all alike at birth, there are certainly very wide differences between them now. Moreover, there is a perfectly gradual transition in brightness from one extreme to the other. It is not a question of a few stars being very much brighter or very much fainter than the great uniform majority. Every stage of luminosity, from the highest to the lowest, is well represented, so far as can be ascertained from the limited amount of information that has been accumulated with regard to absolute stellar magnitudes. Evidently we are here in the presence of knowledge of very great importance. We must leave for a future chapter, however, the discussion of its meaning. At present it will be sufficient to remark that it must be taken in conjunction with other messages of starlight before its full significance can be realised.

Turning now to the question of colour, probably the first thing that will strike us is that there seems to be no possibility of measuring the colour of a star and expressing it by a number, as we saw was done with respect to brightness. In this, however, we are wrong. In the early days of colour measurement, such a classification was attempted by constructing a rough arbitrary scale, in which the bluest stars were numbered 0, and the reddest 10, and the numbers were assigned according to the judgment of the observer. Here, it is true, there was no possibility of precision or freedom from individual bias, and although such a classification was better than none at all, very little definite meaning could be attached to the colour-number of a star. At the present time, however, a much more delicate method of colour measurement is adopted; in fact, three distinct methods have come into general use, and the results which they give are quite consistent with one another. The colour of a star is expressed by its *colour-index*, its *effective wave-length*, or its *exposure-ratio*. We will see briefly what each of these terms means.

The estimation of colour by means of colour-index depends on the fact that the apparent magnitude of a star, as we have defined it, is determined, not only by the brightness of the star and its distance from us, but also by the instrument which is used to receive the light which the star sends out. We might, for example, compare the star under examination with a standard star by means of the eye or by means of photography, and the results we obtain might differ widely, in a manner depending only

Photo by *Huggins.*

SPECTRUM OF VEGA.

This is a typical spectrum of Harvard Class A. The very strong absorption lines, forming a regular series, are due to hydrogen. Sirius and Castor are other examples of stars having this type of spectrum.

on the colour of the star. For, as we know, the eye is sensitive to the whole of the visible spectrum, whereas an ordinary photographic plate is scarcely affected by the red, yellow, and most of the green rays, but, on the other hand, registers the ultra-violet light, which the eye cannot see, as well as the visible blue and violet light. If, therefore, a star has most of its radiation near the red end of the spectrum, it may appear as a bright red star to the eye, but as a very faint object on the photographic plate. A star having most of its radiation in the blue, however, may appear bright to both eye and plate, or, if the radiation extends in strength far enough into the ultra-violet, the star may even appear brighter to the plate than it does to the eye. The difference evidently depends on what region of the spectrum contains the greatest part of the radiation from the star, which is simply another way of saying that it depends on the colour of the star. Accordingly, the difference, *photographic* minus *visual* magnitude, is a direct measure of colour, and is therefore known as the star's *colour-index*. If the difference has a large positive value, the star is very red (remember that, the brighter the star, the smaller is the number representing its magnitude); if, on the other hand, the difference has a zero or negative value, the star must be blue. Colour is thus estimated on the same scale—the scale of magnitudes—as is brightness. Since a direct comparison between the photographic and visual scales is not possible, the "zero-points" of the two scales have to be chosen independently. They are, by common agreement, made such that a certain defined type of blue star has a zero magnitude on each scale. The way is then clear for the determination of colour with the same degree of precision as that achieved in the measurement of brightness.

A second method of colour estimation is the direct determination of the region of the star's spectrum which most strongly affects a photographic plate sensitised for all colours. A spectrum of the star is obtained with exceedingly small dispersion, so that it looks very little different from the direct photograph of the star itself. This spectrum will affect the photographic plate most strongly at the point corresponding to the light in it which has the greatest intensity, and therefore which has the greatest effect in determining the colour of the star. The wave-length of the light at this point is called the *effective* wave-length; the larger the effective wave-length, the redder is the star. It is found that the relative colours of two stars, as determined by colour-index and by effective wave-length, are, in general, in the same order, and the two methods are therefore consistent with one another.

The third method—that of exposure-ratios—is due to Professor Seares, of the Mount Wilson Observatory, who has done a great deal of very valuable work in connection with the standardisation of magnitude and colour measurement. Two photographs of a star are taken—one on an ordinary photographic plate, and the other on a plate which is sensitive to the whole of the visible spectrum, and is arranged, by combination with suitable light filters, to record images having the same relative intensities as those estimated by the eye. The latter kind of plate can evidently be substituted for the eye in the determination of visual magnitudes, and it is, in fact, so used. Its scale of magnitudes is called the *photovisual* scale, and is superior to the visual scale in two respects—first, it is independent

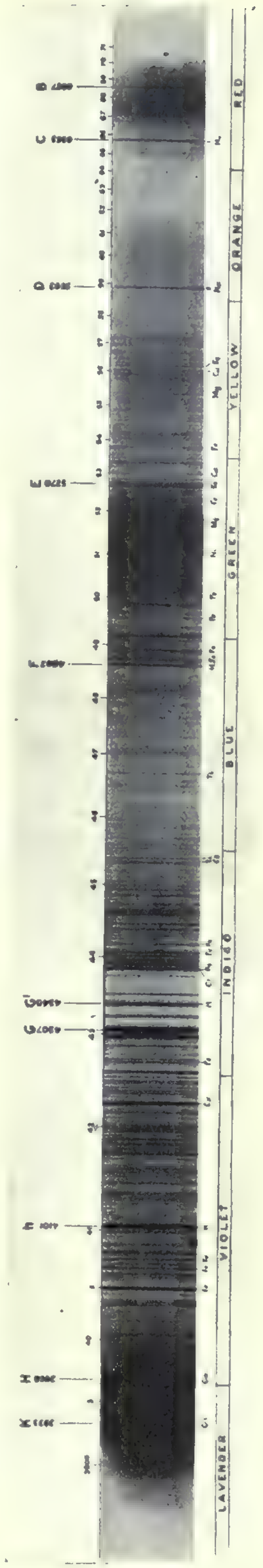
of the peculiarities of particular observers ; and, second, it extends the application of the measurements to stars too faint to be seen by the eye. For the determination of colour by the exposure-ratio method, however, magnitudes are not directly measured. The two plates mentioned above are exposed successively to the same star under exactly the same conditions, and the colour is measured by the ratio of the times of exposure necessary to produce images of the same intensity on both of them. It is clear that a red star will take much longer than a blue star to impress the ordinary plate as strongly as it does the photovisual one, so that it will readily be understood that the method gives an actual criterion of colour.

When the results of colour measurement are analysed, it is found that, as with magnitudes, there is a gradual transition from one extreme to the other. From the reddest stars, which Secchi, in the middle of the last century, likened to drops of blood, to the bright blue stars found in the constellation of Orion and elsewhere, there is a continuous range of colour, without a break and without a marked preponderance of stars of any one colour. This is another example of the continuity of phenomena which is one of the most significant facts of modern Astronomy, as it was shown to be more than sixty years ago in the realm of Biology.

But we must hasten to the consideration of stellar spectra, which are, after all, a more detailed and analytical statement of the colours of the stars. The spectrum differs from the other two qualities of starlight in being an essentially modern discovery. Magnitudes were measured in the time of Ptolemy. Colour, though no attempt seems to have been made to classify it at so early a time, was noticed as a characteristic by which the stars could be partially distinguished. But it was not until the beginning of the Nineteenth Century that the spectrum of a star was first seen, and no serious study of stellar spectra was undertaken until the middle of that century, when Secchi, Huggins, Rutherford and others inaugurated the new era in which we are now thoroughly immersed.

At the very beginning of the work it was noticed that the spectra of the stars were not all the same. Some stars gave spectra almost indistinguishable from the spectrum of the Sun, while others gave quite a different kind of spectrum. Vega, for example (*see* page 482), appeared to show only a regular succession of very pronounced dark lines, most of which had never been matched in the laboratory at all. A new field of activity was opened up in the accumulation and classification of as many stellar spectra as possible.

In spite of the variety of the results obtained, there was one striking uniformity—the overwhelming majority of the stars gave spectra of the absorption type ; that is, a background of continuous spectrum on which dark lines appeared. What this meant has been explained in Chapter I ; a star evidently consisted of a very hot central core emitting light which alone would form a continuous spectrum, surrounded by a cooler, but still luminous, atmosphere, which absorbed certain rays from the light of the interior and thereby gave rise to the dark lines perceived. The almost universal



THE SOLAR SPECTRUM.

The solar spectrum is a typical spectrum of Class G. The hydrogen lines (marked C, F, G', *h*) are not nearly as conspicuous as they are in the earlier classes, while the two lines, H and K, of calcium, are exceedingly intense.

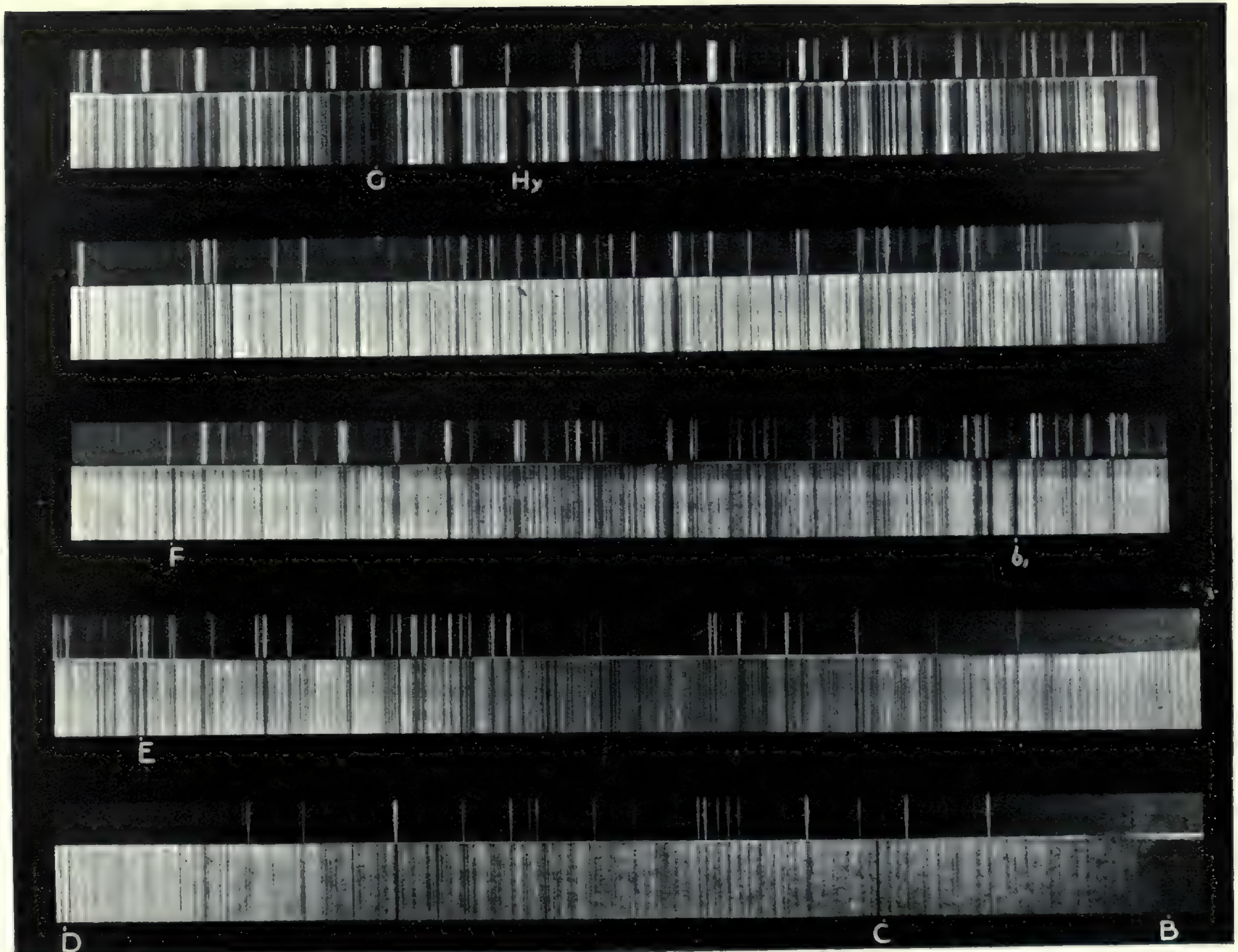


Photo by] [Mount Wilson Observatory.

SPECTRA OF THE STAR ARCTURUS AND IRON.

The upper spectrum is the spectrum of iron taken in the observatory, and the lower is the spectrum of Arcturus. Arcturus has a spectrum of Class K—a little later in the Harvard sequence than the solar spectrum. The presence of iron in the star is clearly shown in this picture, and accurate measurements of the positions of the lines show also whether the star is moving towards or away from the Earth. The lines marked by letters appear as prominent lines in the solar spectrum.

occurrence of this kind of spectrum showed that nearly all the stars, including our Sun, were constructed in very much the same way. But there were a few stars which gave *bright* lines on a fainter continuous background. In some spectra the bright lines were accompanied by dark ones, while in others they existed alone. These bright line stars have, from the moment of their discovery, presented some of the most fascinating problems to the astrophysicist, towards the solution of which very little has yet been done. They are known as Wolf-Rayet stars, in honour of the two observers who first detected them. We can do no more than mention them here, for they are relatively too few in number to influence, to any great extent, the wider generalisations that are aimed at in the study of the sidereal universe.

It was seen, too, at an early stage, that a large number of lines in stellar spectra were identical in position with lines which could be produced from familiar terrestrial substances in the laboratory. This meant, of course, that those substances were present in the atmospheres of the stars. With regard

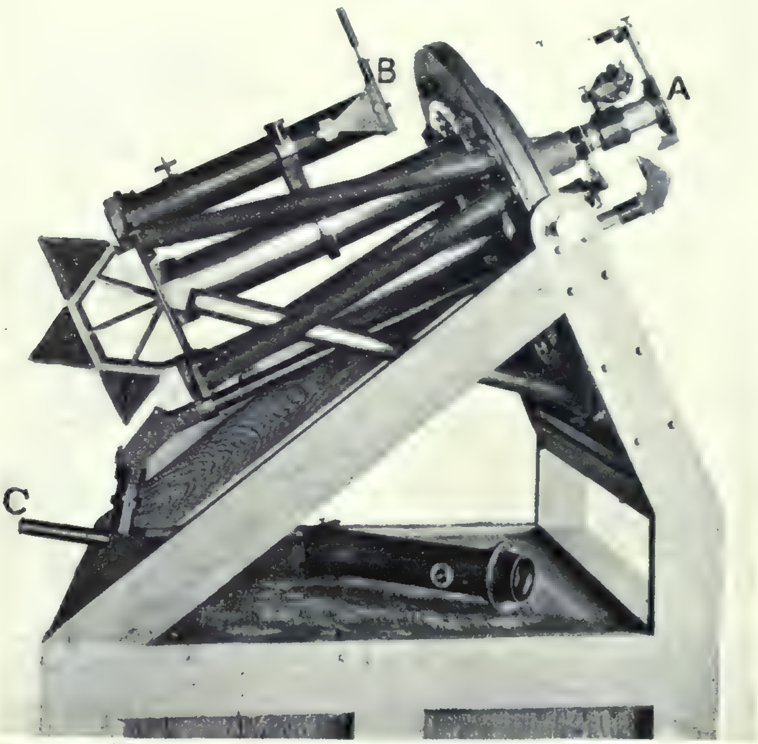
LARGE LITTROW SPECTROGRAPH AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON.

This is a special form of spectrograph used in obtaining high dispersion. When used, it is completely enclosed in a long wooden box. On the left are the slit and the photographic plate. The light entering the slit is sent through the lens and prism and reflected back again, as a spectrum, by a mirror to the photographic plate.

to the lines which were left over, there were two possibilities: either they were lines of substances unknown on the Earth, or else they were lines producible from terrestrial substances by some method not up to that time devised. We can see now that these two possibilities were open, but at the time when the phenomena were first recorded, the second one was not admitted. It was believed that the spectrum of an element was unique and unalterable; that no matter how a substance was made to emit radiation, it always emitted the same radiation, in greater or less intensity according to the conditions of its excitation. It was Lockyer who first challenged this assumption. He showed, by irrefutable evidence, that it was possible to make a single element produce greatly different spectra by raising it to different temperatures, and pointed out that, in consequence of this fact, the spectrum of a substance might be made to indicate, not only the chemical composition, but also the temperature of the substance, within a fairly narrow range. We shall have more to say on this point shortly, but for the moment we will observe only that it gave an alternative to the assumption that in the stars

there were many substances unknown on the Earth. Later researches have amply justified the belief that this alternative represents the truth. At the present time, most of the lines in stellar spectra have been identified, and those that remain over are, for the most part, regarded as lines that will probably in the future be obtained from familiar substances. There is very little doubt that essentially the whole of the matter in the universe is formed into the ninety or so elements which are included in the chemist's table.

The next point to be noticed was that, despite the variety shown by stellar spectra, it was possible to arrange the spectra in a continuous sequence. From one type of spectrum to the next in this sequence, the change was exceedingly small, so that in spectra, as in magnitudes and colours, the law of continuity was seen to reign. The way to classify spectra was therefore obviously to divide this unbroken sequence into a number of arbitrary divisions, and to assign to each division a distinctive number or letter. The earliest classifications, by Rutherford and Secchi, were based on this principle. According to Secchi's system, the spectra were divided into four *Types*. Type I comprised the stars with simple spectra, consisting of lines then mostly unknown, but now traced in the main to helium or (as in Vega, which we have previously mentioned) to hydrogen. Type II contained the stars with many-lined spectra, like the Sun. The spectra of Type III contained bands, or flutings, which Fowler, in 1903, traced to titanium oxide. Type IV contained flutings arising from carbon and its compounds. The bright-line stars were subsequently grouped into a Type V.



By permission of *The Yerkes Observatory.*

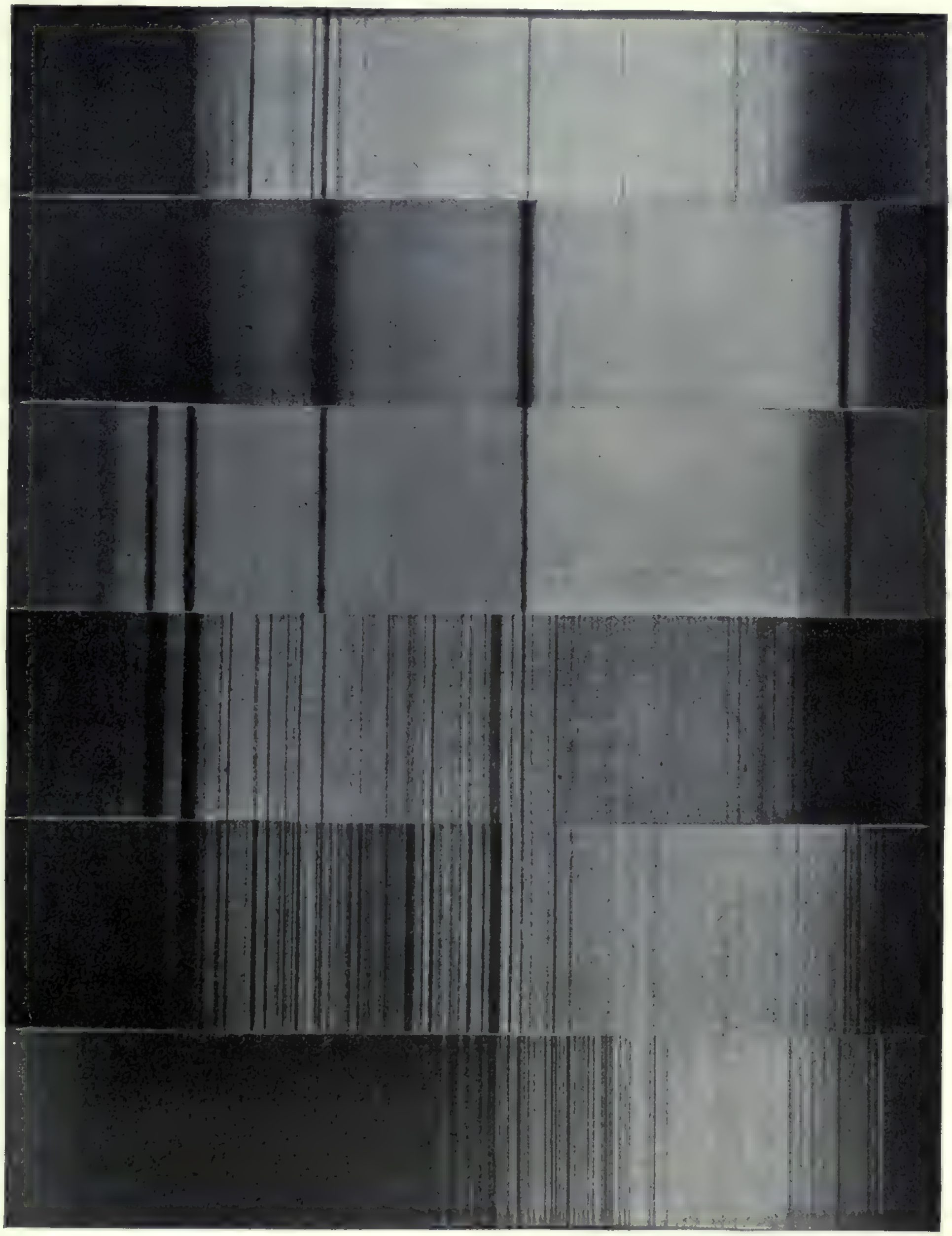
THE BRUCE SPECTROGRAPH OF THE YERKES OBSERVATORY.
The image of the star is focussed by the large telescope on the slit at A. The spectrum produced by the train of prisms is photographed at B. The eyepiece C allows the observer to make sure that the image remains on the slit throughout the exposure.

Secchi's classification is still often referred to in astronomical literature, but, for detailed work, it has been replaced by the system adopted at the Harvard College Observatory in an extensive study of stellar spectra undertaken as a memorial to the late Dr. Henry Draper. This system is generally referred to as the Harvard, or Draper, classification, and the succession of types which it includes is known as the *Harvard sequence*. The great majority of the stars fall into six classes, denoted by the letters B, A, F, G, K, M —relics of what was originally an alphabetical arrangement. Detailed study shows that there are probably two branches of the main sequence—first, two successive classes, R and N, branching off at G, and second, a small class S, leaving the main sequence at K. There remain the bright-line stars, which are included in a class O and placed at the

head of the sequence. The complete Harvard sequence of spectra, as it now stands, is therefore as follows :—

R, N.
O, B, A, F, G, K, M.
S.

Secchi's Type I corresponds approximately to classes B and A ; Type II to F, G, K ; Type III to M ; and

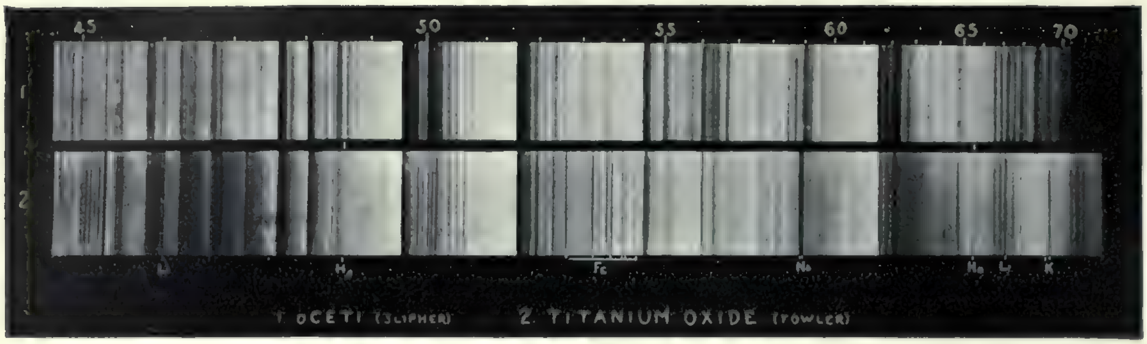


B — ε Orionis (Aluitam).
A — α Canis Majoris (Sirius).
F — α Carinae (Canopus).
G — α Aurigae (Capella).
K — α Boötis (Arcturus).
M — α Orionis (Betelgeuse).

Photo by] [*Harvard College Observatory.*

THE CHIEF TYPES IN THE HARVARD SPECTRAL SEQUENCE.

Nearly all recorded stellar spectra belong to the type represented in this photograph, or to intermediate types. The characteristic lines of the B type are those of helium. The strong hydrogen lines in the A type spectrum gradually become weaker in the succeeding types. The increasing complexity of the spectra after type F is due to the appearance of multitudes of metallic lines. Class M spectra are not well represented in the region illustrated here.



SPECTRA OF THE STAR o CETI (MIRA) AND TITANIUM OXIDE.
The characteristic feature of spectra of Class M, to which Mira belongs, is the predominance of flutings due to titanium oxide. The identity of these flutings was established by Fowler in 1903, and is shown clearly in this photograph.

Type IV to N. R and S are small classes which Secchi did not distinguish. The Sun is a typical star of class G. Examples of these types are shown in some of the illustrations. With regard to the illustrations in which the gradual transition is not obvious, it must be remembered that the spectra selected cannot, of course, represent the whole of a class. Each class itself is sub-divided on a decimal scale —thus, B8 denotes a star eight-tenths of the way from B to A (generally written B_0 and A_0 respectively) —and when the whole series is considered the continuity of type is obvious. The particular feature of the spectra selected by the Harvard observers as a criterion for distinction is the relative intensity of the most prominent lines. Thus, the passage along the sequence of K spectra towards M is marked by a gradual appearance and intensification of the titanium oxide bands which appear at their greatest strength in the later divisions of class M. Other slight differences, which we shall refer to presently, are noticeable in the spectra, but these are ignored in the classification: a star is classified within class K or M by the prominence of the titanium oxide bands, and by very little else.

Now, what are the salient features of this series of spectral classes? Omitting the smaller classes, for lack of space, we will confine our attention to the main sequence B, A, F, G, K, M; since more than ninety-nine per cent. of stellar spectra are included in these classes, we are losing very little in generality by thus restricting ourselves. If we take up a purely chemical point of view, as the earliest observers did, we shall have merely to say that, in going from B to M, we find the most prominent substances represented in the spectra to change from helium to hydrogen, hydrogen to the metals (particularly calcium), and the metals to compounds (mainly titanium oxide). If, further, we assume, with most of the pioneers in this work, that all the substances present in a star's atmosphere must show their spectrum lines with intensities roughly proportional to the relative amounts of the substances there, we shall conclude that the earliest type stars (as stars at the beginning of the sequence are called) contain little but helium or hydrogen, while the late type stars contain a great variety of substances. But, at the present time, fortunately, neither the purely chemical point of view nor the assumption we have mentioned is possible. We must consider the physical conditions in the stellar atmospheres also, and it is necessary that we should digress for a moment in order to explain how a spectrum depends on the physical conditions of its production.

When a substance—say, a piece of thallium, is made luminous in an electric arc, it gives a certain spectrum (*see* page 490). If the substance is used as the electrodes in a condensed electric spark, another spectrum is produced, which is only in part identical with the former one. There are some lines common to both spectra, but the spark spectrum contains also some new lines, while some of the arc lines are weakened or disappear altogether. The significance of this change was first pointed out by Lockyer. He attached a special importance to the lines which were strengthened, or which appeared for the first time, in passing from the arc to the spark, and gave them the name of *enhanced* lines. He attributed their existence to the effect of a higher temperature than that necessary to produce the ordinary arc lines, and he imagined a condition of temperature in which a substance would produce

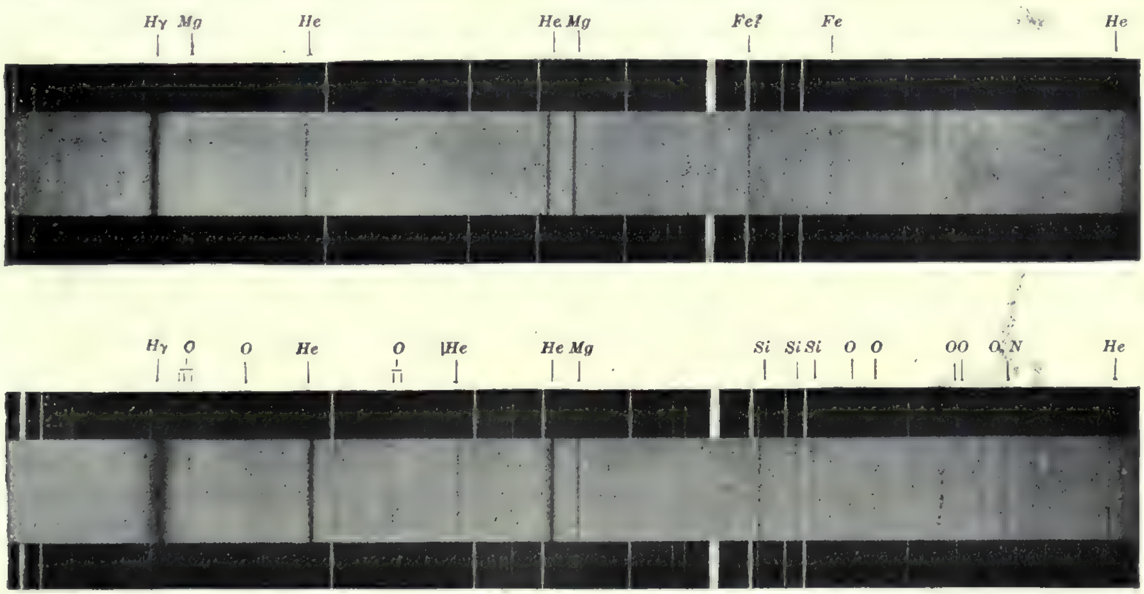
THE STARS FOR NOVEMBER.

"Our plate shows the aspect of the sky as seen, looking North and South, from Westminster Bridge; but the positions of the stars will be practically the same for any place in the latitude of Great Britain.

The constellations will appear in the positions shown on November 1 at about 11.30 p.m. (Greenwich Mean Time).

its enhanced lines alone, and so yield a spectrum quite unlike the arc spectrum with which everyone was familiar. This condition had not been attained on the Earth, not necessarily because it was impossible to reach the required temperature, but because the spark was always surrounded by an envelope of cooler vapours, which added the lower temperature lines to the enhanced lines produced in the centre of the spark. It followed, however, from Lockyer's idea, that the absolute identity of a celestial spectrum with a terrestrial one was not necessary in order to establish the presence of the corresponding substance in the heavenly body. Since the distribution of temperature in the atmosphere of a star might be quite different from that in terrestrial sources of light, there might be quite a different association of ordinary and enhanced lines in the two spectra. If, however, the ordinary and enhanced lines were carefully sorted out, there would be no difficulty in estimating, not only the chemical composition, but also the temperature, of the atmosphere of a star.

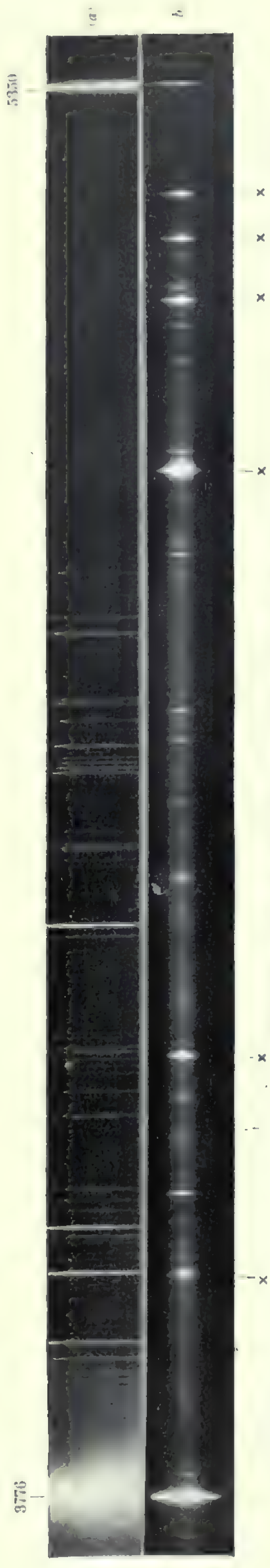
It should be explained, in order to make the conception clearer, that modern researches have tended to confirm Lockyer's views in their general form. It is believed that the spectrum of a substance is the result of processes taking place in the ultimate atoms. An atom is pictured as a sort of solar system, with a central nucleus of positive electricity, surrounded by a number of revolving electrons—units of negative electricity. The total amount of positive electricity forming the nucleus is, in the normal atom, exactly equal to the total amount of negative electricity in the satellite electrons, and one element is distinguished from another merely by the amount of this electricity, and therefore by the number of revolving electrons. The hydrogen atom has only one electron revolving round the nucleus; the helium atom has two, and so on—the atom of the heaviest known element, uranium, having as many as ninety-two. Now, the ordinary spectrum of a substance is believed to be emitted when the satellite electrons undergo certain definite kinds of movement; the higher the temperature, the greater the number of movements they can execute, and the greater the number of lines in the spectrum—up to a certain point. When the temperature reaches a certain stage, the agitation which it causes among the atoms results in the detachment of an electron from among the satellites. The atom is then left incomplete (it is said to be *ionised*), and it is believed that the enhanced lines are due to the movements of the electrons which still remain. There is thus a distinct difference of origin between the ordinary lines and the enhanced lines of an element—almost as great a difference as that between the



By permission of [*The Yerkes Observatory.*

SPECTRA OF B-TYPE STARS.

The upper spectrum is the spectrum of Rigel, which is intrinsically one of the brightest stars in space; and the lower spectrum is that of β Canis Majoris. Each spectrum has a titanium comparison spectrum on either side. The sources of the chief lines are indicated by their chemical symbols (H = hydrogen, He = helium, Mg = magnesium, etc.).



SPECTRUM OF THALLIUM—(a) ARC, (b) SPARK.

Lines which appear in the spark spectrum of a substance, and are weaker or do not exist in the arc spectrum, are called *enhanced* lines. The lines marked **X** are enhanced lines. (The narrow band along the centre of (b) is due to air and should be ignored.) The lines at wave-lengths 5350 and 3776, which are stronger in (a) than in (b) are arc lines.

ordinary spectra of two different elements. The reason why we do not, in the laboratory, get the enhanced lines totally free from ordinary ones is that we cannot ionise all the atoms in our sources of light. Those which are ionised give enhanced lines ; the others give ordinary lines, and the resulting spectrum is the sum of the two sets. In the hottest stars, however, enhanced lines are shown free from the ordinary ones. One other point should be mentioned before we return to the characteristics of stellar spectra ; namely, that the temperature at which ionisation takes place is different for different elements. It is comparatively low for some elements, such as calcium, for example, but very much higher for helium and hydrogen. This is an important point, for, as we shall see, it has a great deal to do with the explanation of the succession of types in the Harvard sequence.

We can now examine the chief features of the succession of stellar spectra from a more advantageous point of view. It appears that the general order of change, from the earliest to the latest types, is the gradual replacement, as the most prominent substance, of ionised helium by ordinary helium, ordinary helium by ordinary hydrogen, ordinary hydrogen by ionised metals, ionised metals by ordinary metals, and ordinary metals by chemical compounds. In the light of laboratory experience, we can say at once that we are in the presence here of a continuous decrease of temperature. Helium is the most difficult substance to ionise, and we must assume that it is only in the hottest stars that ionised lines of helium can be produced. At the other end of the scale, where compounds occur, we are evidently dealing with comparatively low temperatures, for even at the highest temperatures attainable in the laboratory, all known compounds are broken up into their constituent elements. The order of change from the earliest to the latest spectra of the sequence is, moreover, precisely what we should expect, in the light of experiment, from a gradual decrease of temperature.

It must be borne in mind, of course, that we have been speaking only of the most prominent lines in the spectra. Each type of spectrum contains a multitude of lines, some of which are very faint, but the known origins of all the lines that can be identified are quite consistent with the assumption of a steady decrease of temperature from B to M. The reason why some lines stand out strongly—such as the hydrogen lines in the spectrum of Vega, for instance—is very largely attributable to the fact that, at the temperatures existing in the atmospheres of the stars, the strongest lines of the other substances are in the far ultra-violet region of the spectrum, the light of which is absorbed by our own atmosphere and never reaches us. Owing to this very great disadvantage under which we have to labour, we cannot conclude that, because a substance does not appear to be represented in the spectrum of a star, it does not therefore exist in the atmosphere of the star. Indeed, the great probability is that the atmospheres of all stars are very much alike in chemical composition, and that the

differences observed in the spectra are due chiefly to differences of temperature. This is a very important fact, which was not realised by the earliest observers.

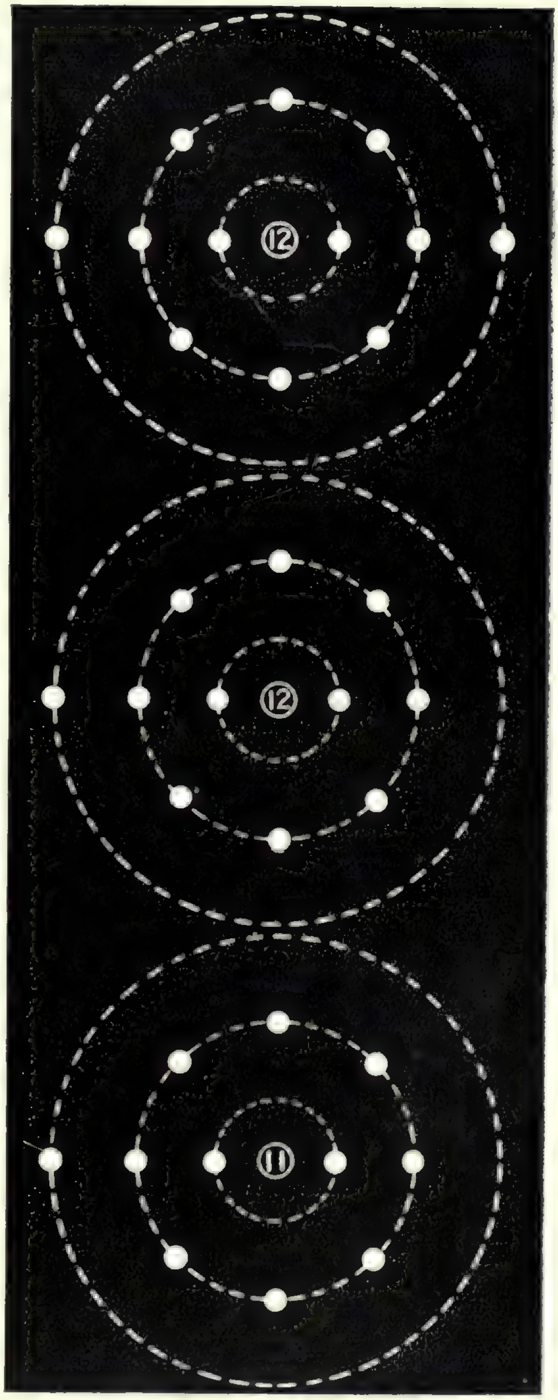
We have said that the differences are due *chiefly* to differences of temperature, and not entirely so, because there are other influences which play some part in the matter. Density, for instance, has an effect on the spectrum of a substance; a decrease of density has the same effect as an increase of temperature, though to a very much smaller extent. Within the main part of the Harvard sequence, with which we are dealing, we can say, without sensible error, that two stars which show the same spectrum, so far as the prominent lines are concerned, have approximately the same temperature. If their atmospheres have different densities, the difference will show itself in less conspicuous details, which have only recently been recognised. Now that they are known, however, they are of enormous importance in extending our knowledge of the conditions in stellar atmospheres, and also in connection with the most comprehensive problems of astrophysics.

The order of temperature deduced in the way we have described has been confirmed by a quite independent method, based on a property of the continuous background of the spectra, and not on the dark lines. It is known that if a body having certain properties be heated to incandescence, so that it radiates a continuous spectrum, the distribution of energy throughout the spectrum depends only on the temperature of the body, in a manner which has been well determined. The hotter the body, the greater the proportion of energy which is thrown into the violet end of the spectrum. Now if we assume that the interiors of stars have the same properties as those bodies which have been experimented on in the laboratory, we can deduce their effective temperatures from a study of the distribution of energy in the spectra. (The phrase "*effective* temperatures" is used to allow for the probability that the temperature varies over a wide range in the interior of a star. The temperature determined in the way we are describing is that which a body of uniform temperature would have if it radiated the same continuous spectrum as that given by the star.) This has been done, and it has been found that the

A

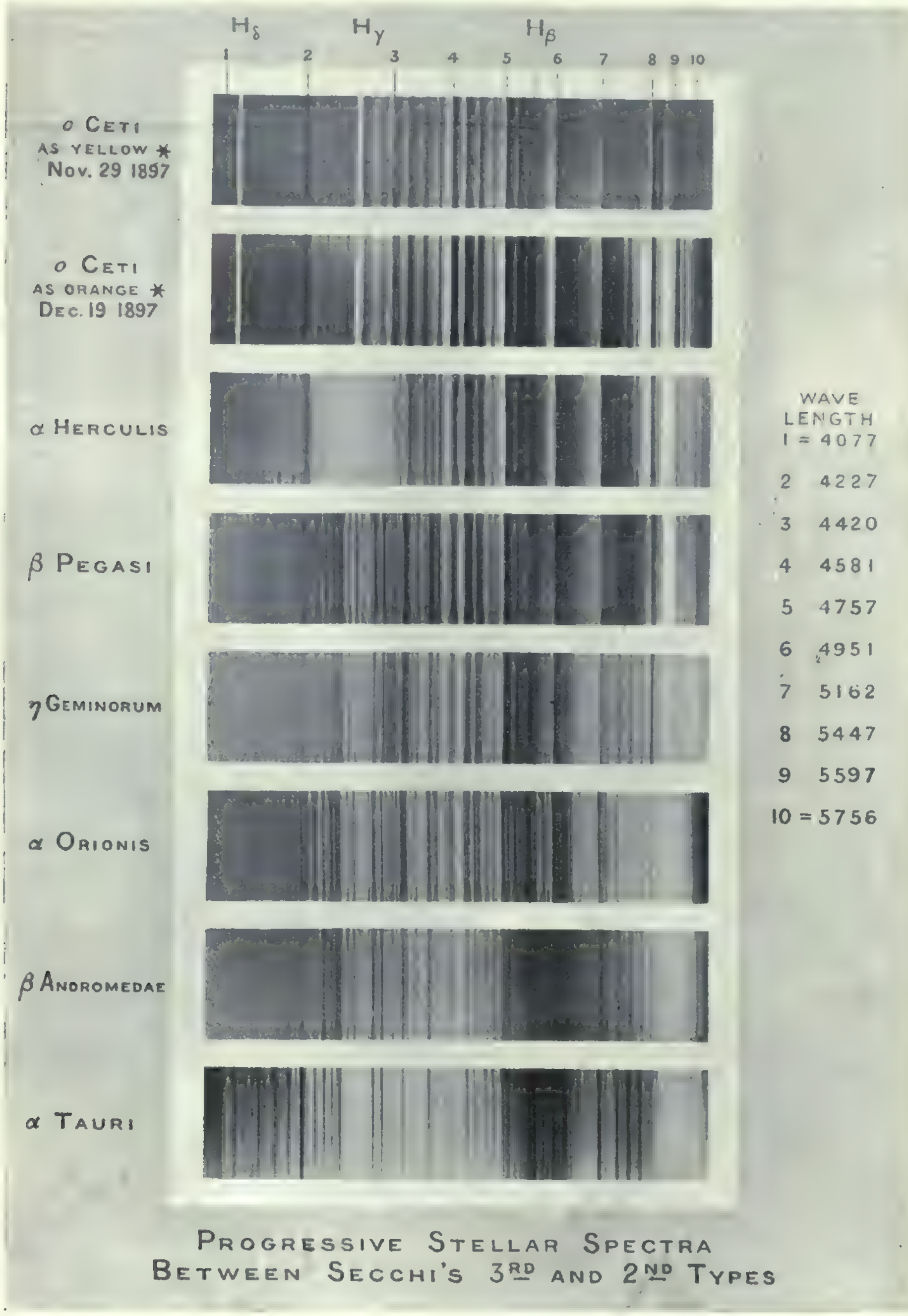
B

C



IDEAL STRUCTURES OF ATOMS.
(A) Ordinary atom of magnesium. (B) Ionised atom of magnesium. (C) Ordinary atom of sodium (diagrammatic). The number at the centre represents the positive electric charge on the nucleus. In all ordinary atoms it is the same as the number of surrounding electrons. It will be noticed that ordinary magnesium differs from ionised magnesium only in the number of electrons, and ionised magnesium differs from ordinary sodium only in the central charge.

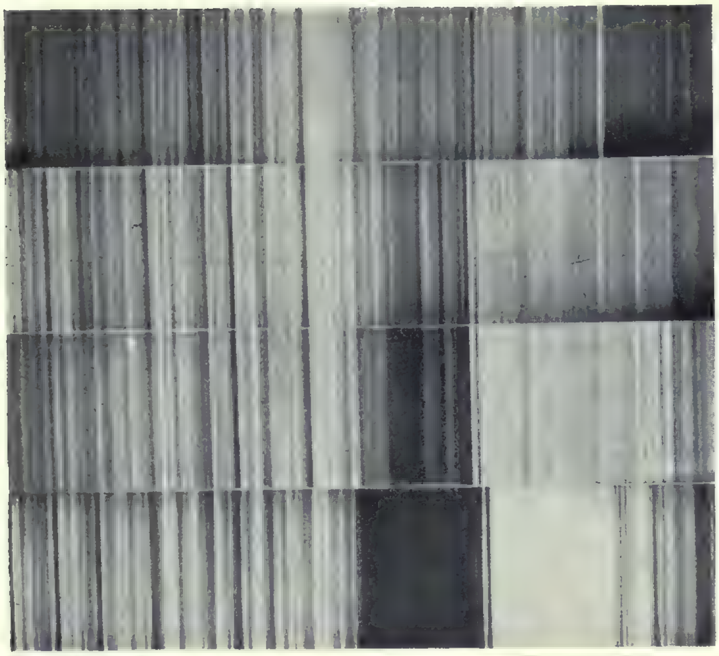
order of temperature shown by this method is in excellent agreement with that determined from the character of the spectrum lines. We should not expect the agreement to extend to the individual temperatures, for two reasons. In the first place, since the spectrum *lines* are produced in the atmospheres of the stars, and the continuous spectra are radiated from the interiors, the temperatures are those of different regions. Secondly, the distribution of energy in the continuous spectrum depends only on the temperature, whereas the spectrum lines, as we have seen, are influenced to some extent by density and other things. But we may quite reasonably expect that the *relative* temperatures of the stars, determined by the two methods, should agree, and this is actually found to be so; the agreement between the actual values, in fact, is closer than would have been anticipated from the conditions of the problem. To give some general idea of the results obtained, it may be said that, from temperatures of 15,000 degrees Centigrade at the top of the Harvard sequence, we descend to temperatures of about 3,000 degrees Centigrade at the bottom. We may regard



Stonyhurst College Observatory.

PROGRESSIVE STELLAR SPECTRA.

This photograph shows very clearly, for a small part of the Harvard sequence, the gradual character of the change from one spectrum class to the next, which is characteristic of the whole sequence. α Tauri belongs to Class K, and the other spectra to successive divisions of Class M. The two spectra at the top represent o Ceti—a variable star—at different times during its period.



By permission of] [*The Yerkes Observatory.*

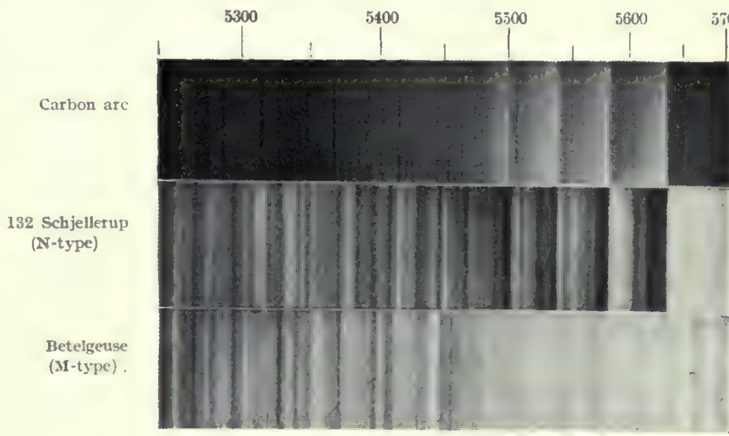
PROGRESSIVE SPECTRA OF STARS OF TYPE N.

In this photograph the gradual change of spectrum within a single class, N, is shown. The progression is marked by the gradual intensification of the dark carbon absorption bands near the centre. These bands are characteristic of this type of spectrum.

these as the temperatures near the surfaces of the stars ; in the interiors, temperatures of millions of degrees are probably attained, though for their determination we have at present to rely on theoretical calculations ; no experimental methods of measurement are known.

The most important and far-reaching fact about stellar spectra is undoubtedly the existence of the Harvard sequence and its message. It has opened our eyes to unimagined avenues into the mysteries of the universe, and it is probable that we are as yet only at the beginning of a realisation of its potentialities. But there are other qualities of the spectra of which we must take account—qualities which have given us information on matters apparently outside the scope of spectroscopy altogether. Incredible as it seems, there is scarcely a single physical or chemical property of a star that is not, in one way or another, expressed by the spectrum. In this respect, indeed, the spectrum swells out pre-eminent among the three voices of starlight. Taken alone, magnitude and colour tell us very little ; their chief significance is seen when they are taken in conjunction with other stellar qualities. But the spectrum not only interprets the messages of other qualities—it has messages peculiarly its own, which, so far as we can see, could be delivered through no other medium. We will see, so far as space will allow, what some of those messages are, and how they help us.

Mention has been made in a previous chapter (p. 65) of the way in which the spectrum shows the motion of a star towards or from the Earth. A star, of course, may be moving in any direction in space, but no matter how it is moving, we can always suppose the motion to be made up of two parts—one along the line joining the star to the Earth, and the other at right angles to that line (*see* p. 495). Now, the second component of the motion is obviously revealed by the change of position of the star in the sky. A long time—fifty years or so—has often to elapse before this change of position becomes



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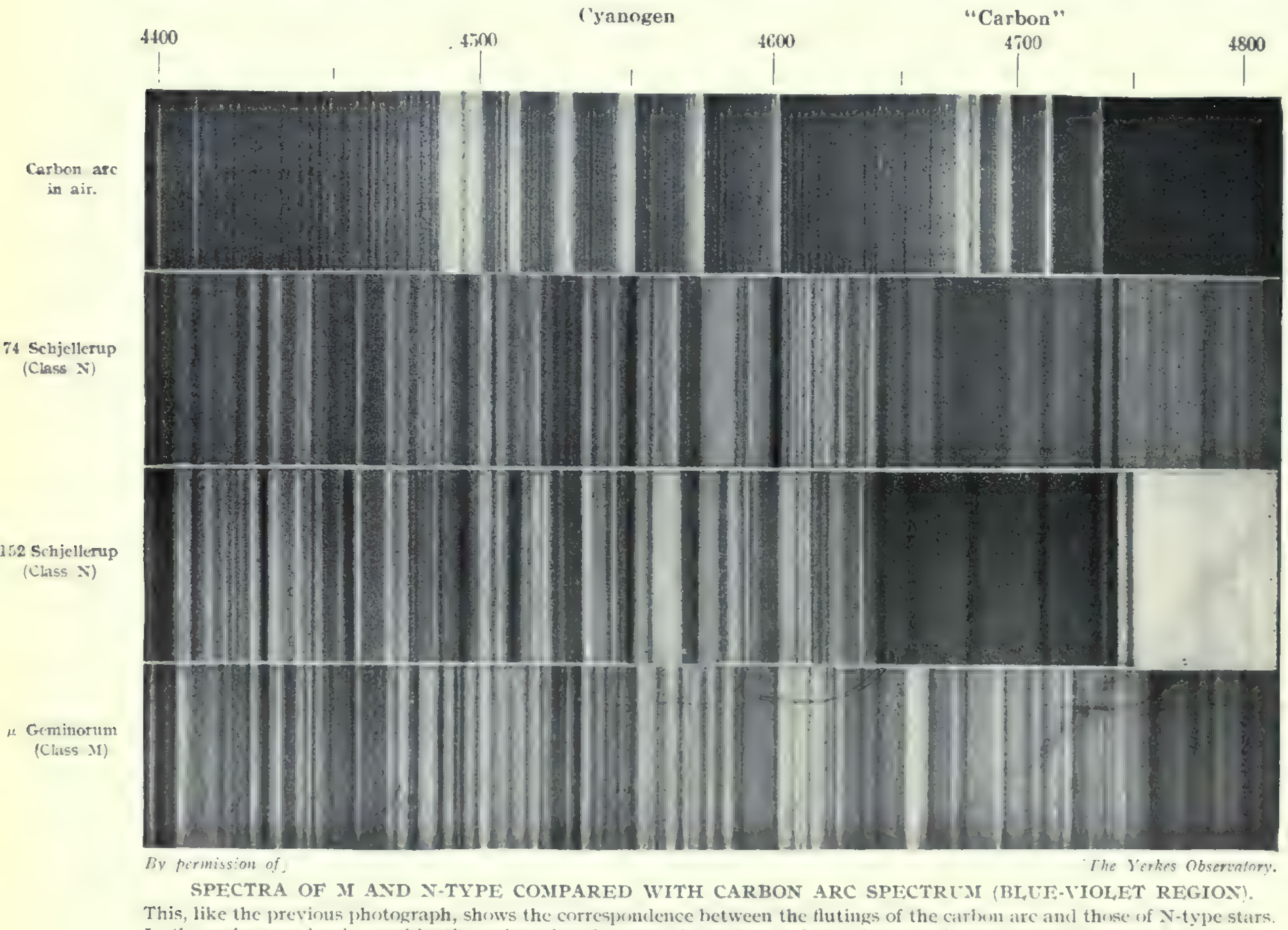
SPECTRA OF M AND N-TYPE, COMPARED WITH CARBON ARC SPECTRUM (GREEN-YELLOW REGION).

This photograph shows the identity between the bands, or flutings, in stars of Type N, and in the carbon arc. The M-type spectrum is quite dissimilar.

measurable, but if we wait long enough we can always determine its value merely by telescopic observation. The change of position is called the *proper motion* of the star, and before the discovery of the spectroscope it was thought to reveal the only part of the motion of the star that could ever be determined on the Earth. But now we know, from Doppler's principle, that the component of motion in the line of sight—the *line-of-sight*, or *radial* velocity—results in the displacement of the spectrum lines of the star as compared with their positions when produced in a stationary source. Accordingly, if we place, by the side of the stellar spectrum, the spectrum, produced in the observatory, of a substance which is present in the star, we can measure the displacement of the stellar lines, and so deduce the radial velocity. By a slight calculation, it is possible to determine, not only the direction of motion—whether it is towards or away from the Earth—but also the actual speed of the star so far as the radial component of its motion is concerned. Combining this with the cross-velocity deduced from the proper motion, we have then a knowledge of the actual velocity of the star in space.

As a result of measurements of this kind, a remarkable fact has been brought to light; the velocities of the stars are in much the same order as their spectra. That is to say, if we take the average velocities of the stars of the various spectral types, we find a steady increase from B towards M. This cannot possibly be due to chance. On the other hand, it is exceedingly difficult to see how the spectrum can have any influence on, or be influenced by, the velocity of a star. It appears, however, that the explanation is this. The more massive a star is, the more slowly, in general, it moves. Also, the spectrum of a star depends to some extent on the mass of the star—a conclusion which has been reached

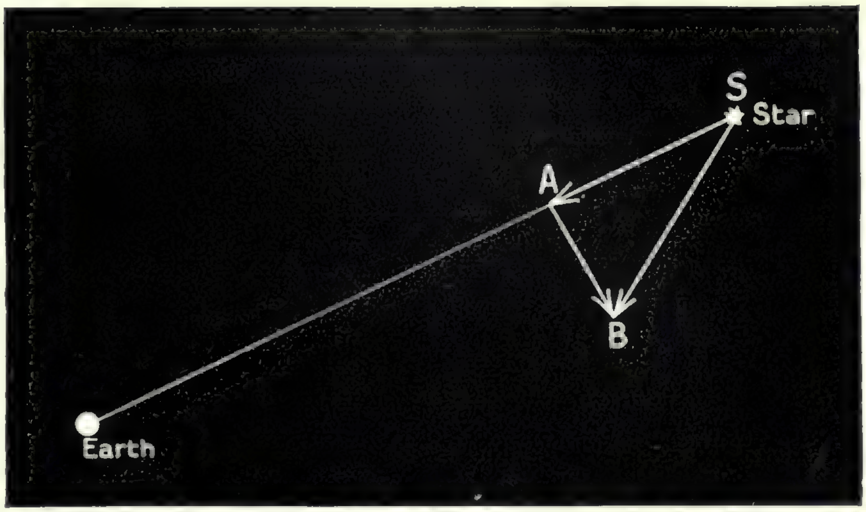


By permission of *The Yerkes Observatory.*

SPECTRA OF M AND N-TYPE COMPARED WITH CARBON ARC SPECTRUM (BLUE-VIOLET REGION).

This, like the previous photograph, shows the correspondence between the flutings of the carbon arc and those of N-type stars. In the carbon arc in air, combination takes place between the carbon and the nitrogen of the air, and the bands in the region 4600–4500 are due to the cyanogen thus formed.

on theoretical grounds. Consequently, there must be an apparent relation between spectral type and velocity, for they are both influenced by mass. The relation, as it happens, takes the form stated, and its discovery has thrown a great deal of light on the general problems of stellar constitution and development. It may be mentioned, although the velocities of the stars vary over a rather wide range, that the average value is of the order of twenty miles per second. The Sun itself, with its planets, is moving through the universe at about twelve miles per second, and this has to be allowed for in determining the velocities of other stars. It has to be remembered that we are making our observations from a moving body, and consequently the velocities which we measure are not the actual velocities of the stars in space.



SB = Space Velocity. SA = Radial Velocity. AB = Proper Motion.

DIAGRAM ILLUSTRATING VELOCITY COMPONENTS OF STARS.
The complete velocity of any star is expressed by two components—the "proper motion" (across the line of sight), and the "radial velocity" (in the line of sight). The former is determined by direct observation and the latter by the spectroscope.

Another use of the spectrum, which has lately come into great prominence, lies in the determination of absolute magnitudes. We have seen that the apparent magnitudes of stars can be measured directly, and that, if we know the distances of the stars also, we can determine the absolute magnitudes. Until recently, however, it was not possible to calculate the absolute magnitudes of many stars, because our knowledge of stellar distances was so limited, and no method was known by which absolute magnitudes could be found without knowing, first of all, the distances of the stars. But a few years ago it was shown by W. S. Adams, of the Mount Wilson Observatory, that there is a very close relation between the relative intensities of certain lines in the spectra of stars and the absolute magnitudes of the stars—a relation which is so reliable that we have now merely to measure the relative intensities of the appropriate lines in order to find the absolute magnitudes with great accuracy. We have seen that one spectral type is distinguished from another, according to the criterion of the Harvard observers, by the relative intensities of the most prominent lines in the spectra. The lines chosen for absolute magnitude determination, however, are not the most prominent lines ; they are lines whose variations of intensity are so inconspicuous that they were not noticed until Adams pointed out their value, and even among stars of the same spectral type the ratio of the intensities of these particular lines shows that there are wide differences of absolute magnitude. It is impossible to over-estimate the importance of this discovery because, not only can we now find the absolute magnitudes of a very large number of stars, but from this information we can deduce the distances of those stars.

For it is clear that a knowledge of the apparent and absolute magnitudes of a star is sufficient to determine its distance, just as in the first instance a knowledge of the apparent magnitude and distance was sufficient to determine absolute magnitude. We are now on the high road to the determination of stellar distances on a scale of which the possibility was not conceived a few years ago, and we cannot yet forecast what the influence of this fact will be on the problem of the structure of the universe.

Yet another application of stellar spectra to matters apparently totally unconnected with them is the detection of double stars. We saw that, in the matter of stellar velocities, the spectroscope came in to show us just that part of a star's motion which we could not determine by ordinary

observation. It is the same with double stars. The farther the components of a double star are separated from one another, the more easily can they be recognised as distinct by the telescope. On the other hand, the nearer they are together, the more quickly do they revolve round their common centre of gravity, and therefore the greater chance is there that the Doppler effect arising from their orbital motion will be discernible. The harder a double star is to detect by the telescope, the easier it is to detect by the spectroscope. We can easily see how the detection is achieved. A star revolving in an orbit is, in general, approaching the Earth during a part of its motion and receding from it during another part. Consequently, its spectrum lines will undergo an oscillation backwards and forwards, owing to the changing Doppler effect. If both components of the double star are bright enough to show lines in the spectrum, we shall therefore have two sets of spectrum lines oscillating to and fro in a period equal to the period of revolution of the stars. When one set is displaced to its greatest distance to the red, the other will be displaced to its greatest distance to the violet, and *vice versa*. As the lines cross one another in their oscillation, there will be a moment when they coalesce and only a single spectrum will be seen. When this sequence of phenomena occurs in a spectrum, it is known that a double star is being observed, even although the star appears to the most powerful telescope as a single point of light.

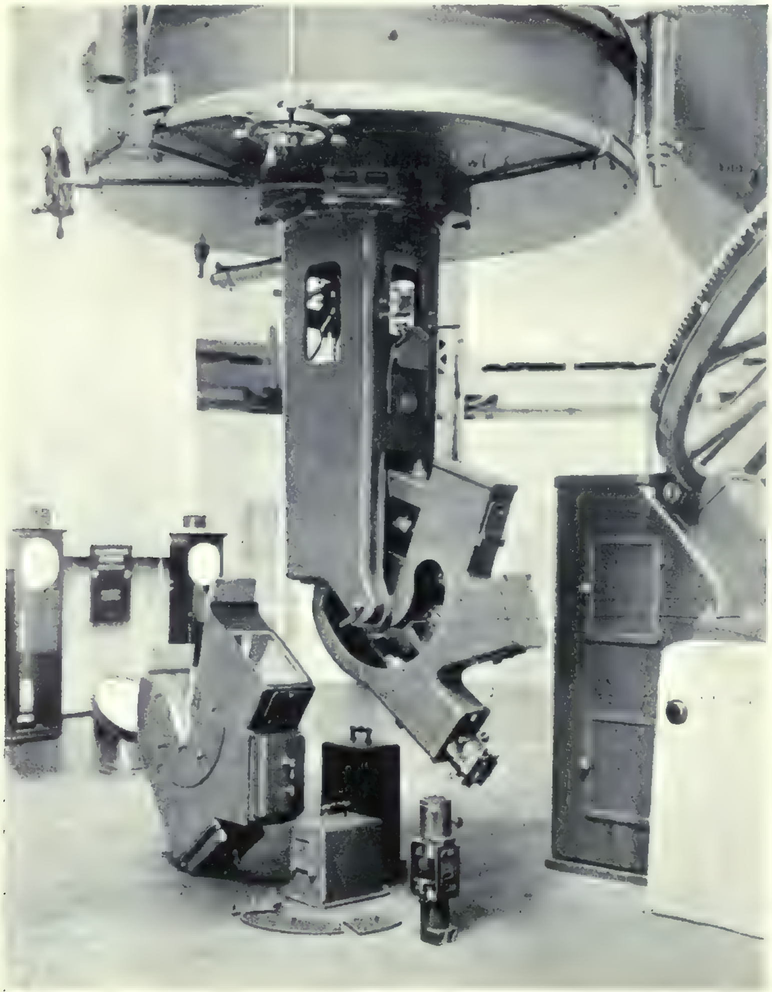


Photo by, *[Dominion Astrophysical Observatory, Victoria, B.C.*

SPECTROGRAPH OF THE SEVENTY-TWO-INCH REFLECTOR, DOMINION ASTROPHYSICAL OBSERVATORY, VICTORIA, B.C.

The telescope to which this spectrograph is attached is the second largest reflecting telescope in the world. It was erected a few years ago, chiefly for the purpose of measuring the radial velocities of the stars.

And it is not necessary that both the stars shall be bright enough to give spectrum lines. If only one of them does so, we shall have a single spectrum with oscillating lines, and that is just as good a criterion of duplicity, generally speaking, as is the double spectrum. A star cannot revolve in an orbit (and consequently give oscillating spectrum lines) unless it has a companion, and though we cannot see the companion, we are perfectly justified in supposing it to exist if we establish the fact that the star which can be seen is revolving in a short-period orbit. Stars which are found to be double by the spectroscope are known as *spectroscopic binaries*. Occasionally, both components of a spectroscopic binary can be seen separate—*i.e.*, the star is a visual binary as well—but the great majority of such stars appear to the eye at the telescope to be single.

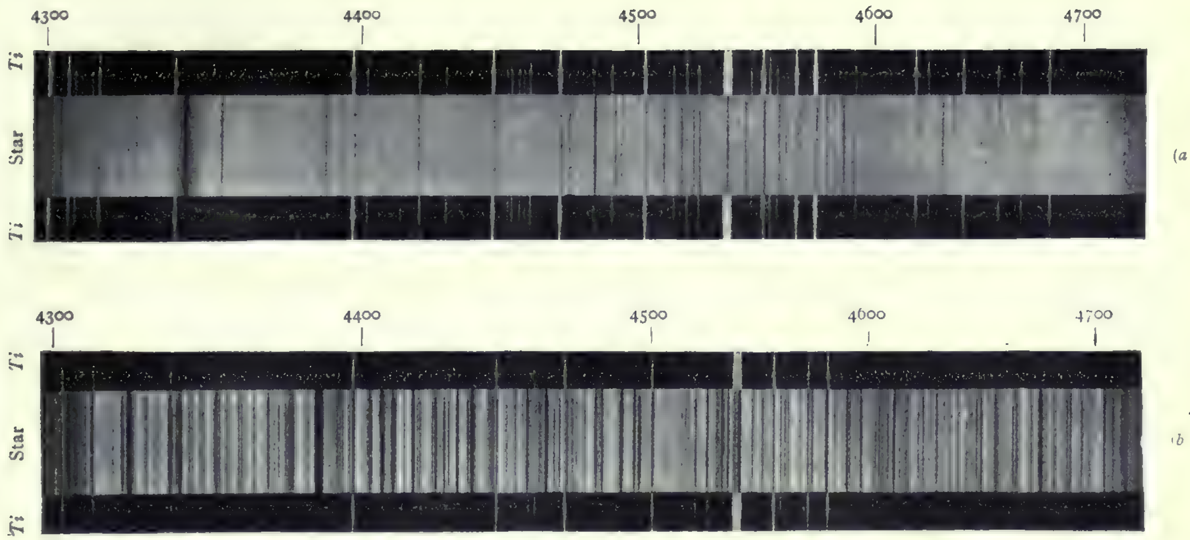


Photo by [*The Yerkes Observatory.*

SPECTRA OF (*a*) η LEONIS, (*b*) ARCTURUS, SHOWING RADIAL VELOCITY DISPLACEMENTS.

The titanium lines in the spectrum of η Leonis are displaced slightly to the red (the right-hand side), as compared with the same lines produced in the observatory, indicating that the star and the Earth were separating at eighteen miles per second. Similarly, the displacement to the violet of the lines of Arcturus shows an approach at eleven miles per second.

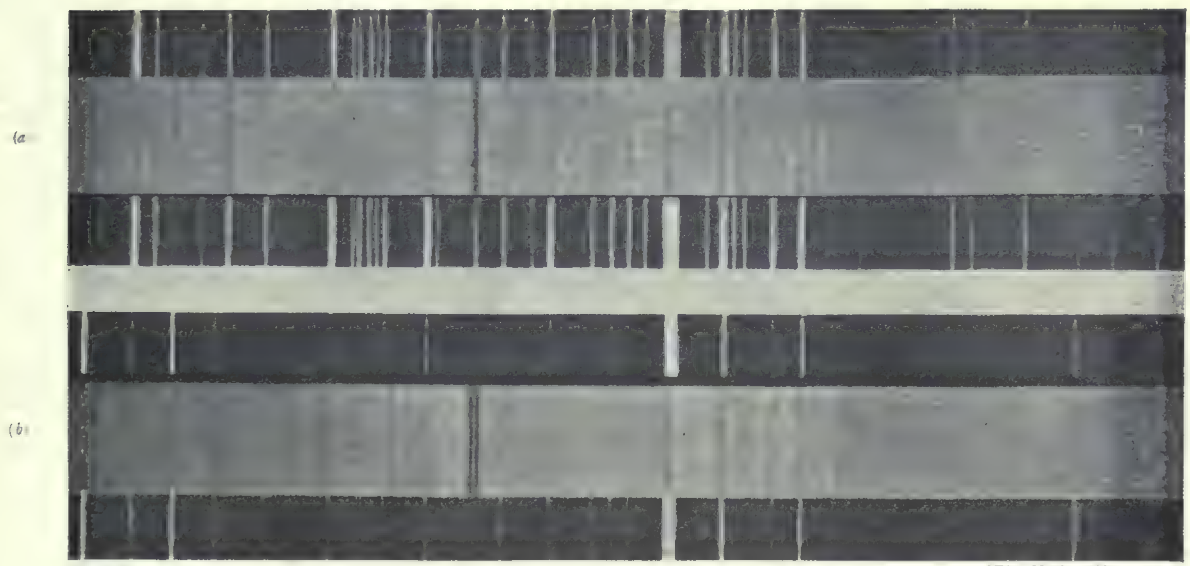


Photo by, [*The Yerkes Observatory.*

SPECTRA OF ζ URSAE MAJORIS.

ζ Ursae Majoris, or Mizar, is a typical spectroscopic binary. In (*a*) the spectrum is shown in the centre (the outside spectra are of titanium, for comparison purposes), when the lines of the component stars are superposed. In (*b*), taken some time later, the lines are shown double. (See text for explanation.)

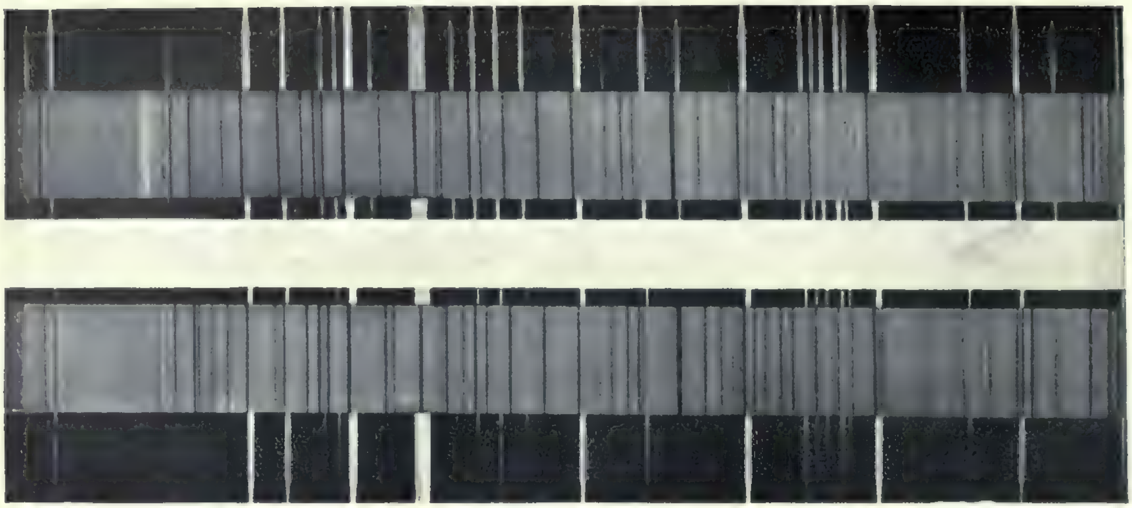


Photo by] [*The Yerkes Observatory.*

SPECTRA OF μ ORIONIS.

μ Orionis is a spectroscopic binary of which only one of the component stars is bright enough to give lines in the spectrum. The periodic change of position of the lines with respect to the adjacent comparison spectrum shows the duplicity of the star.

Such are a few of the ways in which the spectroscope is revealing a new and fuller universe to us. At this point, however, perhaps we ought to make apologies to one of the other messengers of starlight—to magnitude. We have said that, taken alone, magnitude and colour tell us very little. There is one conspicuous set of circumstances, however, in which magnitude by itself can reveal double stars to us. If the plane of the orbit of such a star passes through or near the Earth, there is a periodical eclipse of one component by the other, and at these times the total light that we get from the star is diminished. Such a star as this has, therefore, a periodic variation in magnitude of a particular kind, on perceiving which we know that we are dealing with a double star. Stars of this type are called *eclipsing binaries*, or *eclipsing variables*. The best-known example is the star Algol, in the constellation Perseus. This star was detected as a double in this way before the spectroscopic study of stars was thought of, and subsequent observations of the Doppler effect have absolutely confirmed the conclusion that was arrived at many years before.

But it is, nevertheless, true that the chief value of magnitude and colour records lies in their relations with other characteristics of the stars, particularly spectral type, and we will conclude by a brief consideration of those relations, so far as they lie within our scope. We have pointed out that, with regard to all three of the qualities with which we are concerned—magnitude, colour, spectrum—there is a perfectly gradual transition from one stage to the next among the stars that have been studied. It is now important to consider whether there is any relation between the orders in which the stars are arranged with respect to these qualities. For, although there is a gradual change of magnitude and a gradual change of colour, for example, it does not necessarily follow that particular stars occupy the same positions in the magnitude sequence and the colour sequence. If we find that they do, we shall have obtained a valuable piece of information, which will help us in penetrating to the causes which lie behind the phenomena that we observe.

It is not our purpose in this chapter to discuss this question very fully—that will be done in later chapters—but it is necessary to point out at this stage the problem which exists, and the necessity for discussing it. As an example, let us take the sequences of colour and spectrum. We have found that sequences exist with respect to both these qualities: how are those sequences related to one another? The answer is straightforward: they are very closely, if not exactly, identical. In going from B to M along the spectral sequence, we are going from bluish-white to red stars. The colour-index increases from a small negative value for B stars to about 2 for M stars, and the increase proceeds without a break along the whole sequence. The parallelism is so exact that colour classes of stars

Photo by] [*Dr. W. J. S. Lockyer.*

THE NORMAN LOCKYER OBSERVATORY.

This Observatory was erected in 1912 by the late Sir Norman Lockyer, and is now under the direction of his son, Dr. W. J. S. Lockyer. It is very advantageously situated on the summit of Salcombe Hill, Sidmouth, Devon, and is at present doing very valuable work in determining absolute magnitudes and distances of stars by the spectroscopic method.

have been chosen, similar to the spectral classes. They are denoted by the same letters as the spectral classes, written small instead of in capitals, thus—b, a, f, g, k, m; so that a star of spectral class F, say, has a colour class f, and its colour index is known very closely when its spectral type is known. The meaning of this fact is obvious; whatever determines the spectral type of a star determines also the colour. We have seen that the spectrum depends mainly on temperature; hence the colour also depends mainly on temperature. Or we might, more directly, argue in the opposite way. We know from ordinary experience that when a body is made hotter and hotter, its colour changes from a dull red through yellow to white, so that we can say immediately that the order of stellar colours is the order of stellar temperatures. Since the spectra are in the same order, we derive a confirmation of our previous conclusion that the spectra of stars are determined mainly by temperature. This confirmation is by no means superfluous. The influence of temperature on spectra has not been discovered without a great deal of labour and speculation, and the support of the facts with which we are dealing is very welcome.

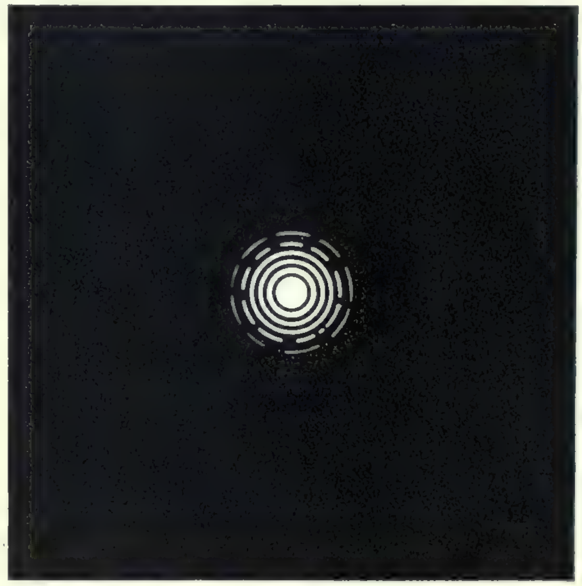
What, now, of the relation between the common colour and spectrum sequence and the magnitude sequence? It is not too much to say that the study of this relation has given a new direction to modern research. The subject is far too big to be dealt with in this article. It opens up the discovery of the existence of "giant" and "dwarf" stars, and leads to a new view of the method of development of the physical universe. In the next chapter, Mr. Peter Doig will show how all this has come about, and to what results it has brought us up to the present time.

CHAPTER XIII.

GIANT AND DWARF AND TWIN SUNS.

BY PETER DOIG, F.R.A.S.

THE astronomers of antiquity considered that the stars were individually of insignificant real dimensions. To their ideas the fixed stars were merely glittering points of light attached to the inside of the hollow vault of heaven, transported across the sky by its daily rotation about a stationary Earth. The absence of effect produced by any change in the locality of the observer on the apparent brightness of the stars showed that the dimensions of the Earth must be small compared with those of the celestial sphere. In the Middle Ages, however, it was thought that a visible disc could be discerned for the more conspicuous ones amounting to as much as one-twentieth or so of the Moon's diameter in the case of those brighter than the first magnitude. Indeed, in the days before the telescope, the famous Danish astronomer Tycho Brahé, and his contemporaries, considered that the great New Star of 1572 showed a disc of fire about one-ninth the diameter of the Full Moon. We now know that this was merely a spurious appearance due to physiological causes in the human retina. The first user of a telescope in celestial scrutiny, Galileo, clearly apprehended that the apparent size of the stars to the naked eye is an optical illusion. This was shown by their remaining as points when viewed through his telescope, unlike the comparatively near planets, which revealed discs even with the low magnifying powers used.



A STAR AS IT APPEARS IN A TELESCOPE.
A star image and its diffraction rings as seen in a powerful telescope. These rings are due to the interference of the crests and hollows of the light waves. If symmetrical and regular they prove the good adjustment and quality of the instrument and the steadiness of the atmosphere.

Nowadays, however, the " man in the street " seems to expect that the giant telescopes of a modern observatory will reveal a shape and sensible dimensions to the fixed stars. Judging by the expressions of disappointment occasionally heard by the astronomer who has charge of one of these instruments on nights of public visitation (such as are commonly stipulated in the terms of gift by the public-spirited millionaire donors of American equipments) something like the Sun or Moon is expected when the eye is applied to the eyepiece of a large telescope turned on Sirius or Betelgeuse. Even with the highest magnifying powers little more than a brilliant point of light is shown, and that little more is just as spurious as the image presented to the naked eye of the pre-telescopic astronomer, being a phenomenon caused by the undulatory nature of light. As described in the first chapter, the detail in a telescopic image is finer the greater the size of the object-glass or mirror employed and the diameter of the spurious stellar disc is inversely proportional to the aperture.

It may be as well to point out that the images of even the faintest stars on photographs such as are published as the illustrations to this work, are all much bigger than the real apparent dimensions would show if they could be recorded. In fact, even a small stellar photographic image may be considerably larger than the whole Solar System, including Neptune's orbit, would appear at the distance involved. Here again the largest instruments give the smallest discs, although the length of exposure of the photograph is an important factor, the diameter increasing with

the time—somewhat as the circle made by a blot of ink on absorbent paper enlarges with added liquid. After unsuccessful attempts to measure the parallax of the fixed stars, it became evident that their apparent dimensions must be extremely small, even if in real size they were much greater than the Sun. As the parallactic displacement, or apparent change in direction arising from the motion of the Earth in its path round the Sun, obviously covers the angular space which would appear to be occupied by a star as large as the Earth's orbit (*i.e.*, about 215 times the Sun's diameter) and as stellar parallax turned out to be so small as to be below the limit of measurement for a long time after the invention of the telescope, it was plain to astronomers that the real disc of any star, however bright, must be very minute.

Speculative thought, in the person of the Rev. John Michell, a contemporary of Sir William Herschel, was able to prove that even in the case of a very bright star the apparent angular diameter must be less than about one-hundredth part of a second of arc (about the size of a halfpenny seen 325 miles away) unless its surface were less brilliant intrinsically than that of the Sun.

This result could be arrived at by comparatively simple calculation, once the relative amounts of light received from the Sun and a star were estimated or measured. The same astronomical thinker, a pioneer in this kind of speculation who has hardly been given the full credit due to him, made another noteworthy suggestion. This was that the " native brightnesses " of the stars (or intrinsic brightness of surface) were according to colour, the white stars having the greatest brilliance and the yellow, or orange, stars being relatively dimmer. Of two stars, emitting the same total quantity of light, one white and the other red, the latter would therefore be the larger in diameter. The star most likely to show a sensible disc would probably thus be one such as Betelgeuse, Antares, Arcturus or Aldebaran. The largest telescopes charged with the greatest possible magnifying powers, having failed to show any definite disc to the brightest or reddest star, other methods of attack were sought and eventually found for the solution of some of the problems involved in the study of the dimensions and evolution of the stars.

The reinforcement provided to the telescope by the spectroscope has enabled the astronomers of the past sixty years or so to do what was beyond the powers of their predecessors. It was now possible to make some attempt to classify the stars according to their spectra, and although at first this classification was purely empirical and arbitrary, it was very soon realised that it probably represented real variety of physical condition dependent on chemical constitution or temperature. In the year 1865, the German physicist, Zöllner, put forward the suggestion that yellow and orange stars are simply white stars in various stages of cooling, and that the redder stars are the older and cooler bodies. Gradually it became the accepted theory that the graduations in spectra were due not so much, if at all, to variety in chemical composition, as to differences in temperature.

The spectra of nearly a quarter of a million stars have now been studied and classified by means of the wholesale methods of the objective-prism, and the vast

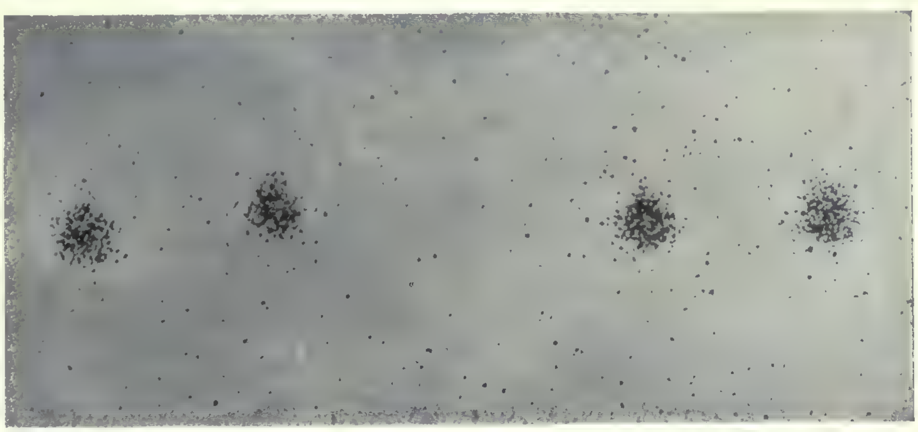
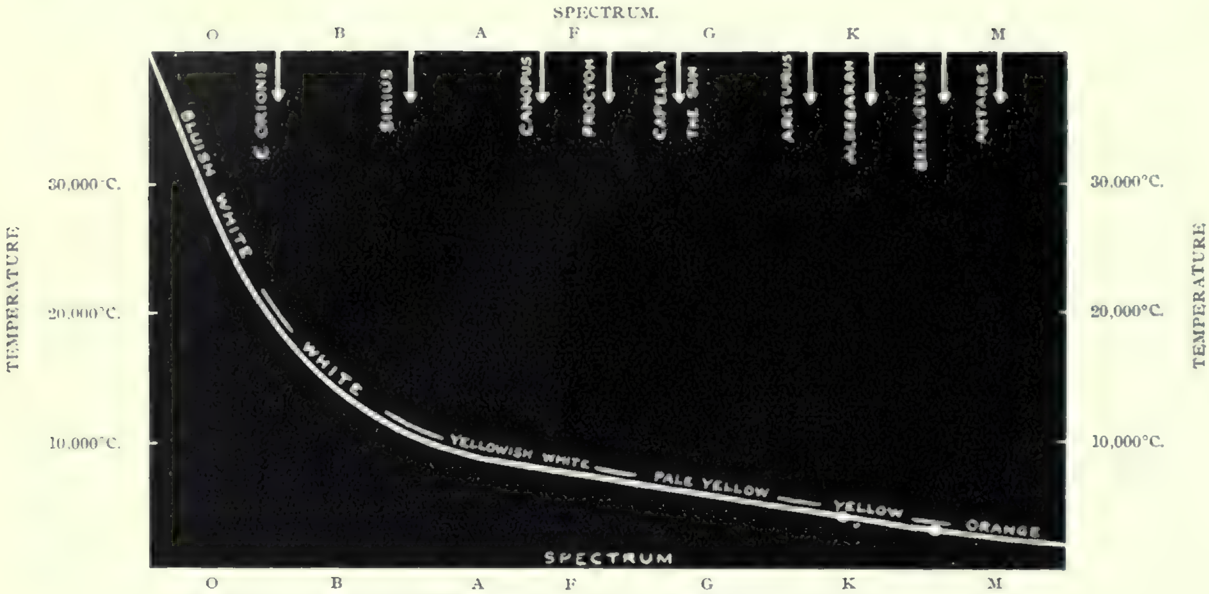


Photo by [*The Lick Observatory.*

MAGNIFIED PHOTOGRAPHIC STAR IMAGES.

Under a microscope the images of stars on the negatives of astronomical photographs appear as groups of blackened grains, which are bigger than the actual discs that the stars themselves would show.



THE RELATION BETWEEN STAR COLOURS, THEIR SPECTRA, AND THE TEMPERATURES OF THEIR ATMOSPHERES.

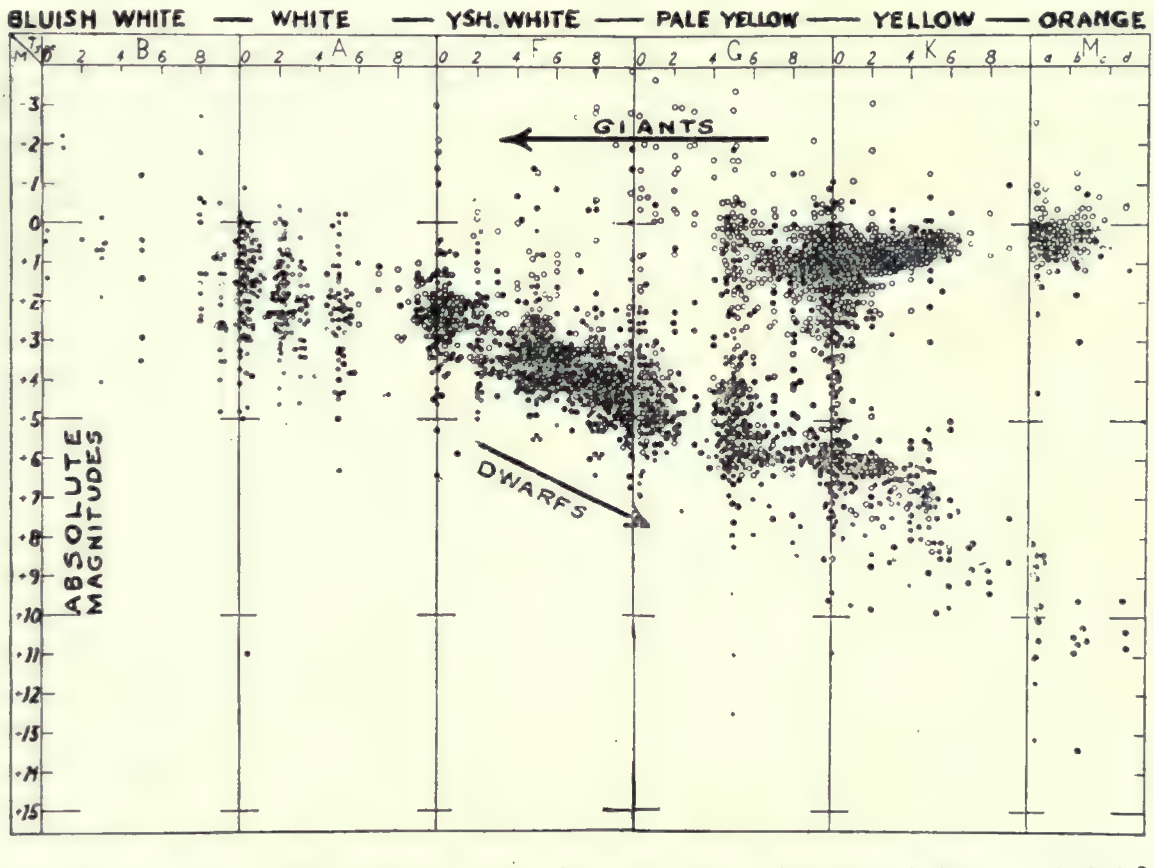
By studies of the stellar spectra and their lines astronomers are able to estimate the temperature of the surfaces or atmospheres of the stars. The whiter a star is, the hotter; or the redder it is the cooler. The positions occupied by ten prominent stars (including the Sun) in regard to colour and temperature are shown. Temperatures in the *interiors* of the stars are believed to be millions of degrees Centigrade !

majority (over ninety-nine per cent.) fall into a sequence which shades off by such uniform gradation as to leave no reasonable doubt that one simple physical cause is mainly responsible for the differences. If more than one cause were operative, then a gradual sequence would be very unlikely. There are other reasons for believing that only one factor is concerned, and that not difference of chemical composition. The dark lines of the spectra show that certain elements are characteristic of particular classes; those of helium, for instance, are predominant in the whitest or bluish-white stars. On the other hand, lines of this element are not seen in solar type spectra, yet they are conspicuous in the spectrum of the Sun's chromosphere. If we could not study the Sun in detail, we might have wrongly concluded that the appearance of helium lines in the spectra of white stars was due to peculiarity of chemical composition. Then again, there are stars belonging to a cluster or connected pair of stars, evidently of common origin, which have great differences in spectra amongst themselves, and it is very unlikely that most of the helium or hydrogen can have collected in certain stars, while their neighbours contain practically all the metals. Astronomers are now generally convinced that the principal cause of the varieties of spectra is difference of temperature in the stellar atmospheres.

That this is so has been demonstrated by the detailed study of the spectral lines and also of the continuous coloured background of spectra in laboratory research work. It is known that the temperature of an oxyhydrogen flame or of the electric furnace is lower than that of an electric arc, which is again less than that of a spark produced by the powerful apparatus of a modern laboratory. Now, the lines which are strongest in the spectra of the orange or red stars are those produced by metals subjected to the oxyhydrogen flame or electric furnace; the lines prominent in the yellow stars are those observed when the electric arc is employed, while the comparatively few metallic lines which are found in the spectra of the white or bluish-white stars are those seen in the spark spectra of the laboratory. It is therefore reasonable to suppose that this order—red, orange, yellow, and white—is one of increasing temperature. From the intensity of the continuous background of the spectra, the same conclusions can be drawn. It is found in laboratory experiments that, at any given temperature, the radiation is greatest at a definite part of the spectrum, and that on either side of this the radiation

falls off according to a definite law. The position of this part moves from the red end to the blue end of the spectrum as temperature increases. By these considerations the following approximate temperatures have been derived for stellar atmospheres: bluish-white stars (B or Orion type), 19,000°C.; white stars (A or Sirian type), 10,000°C.; yellowish-white stars (F or Procyon type), 7,500°C.; yellowish stars (G or Solar type), 6,000°C.; yellow stars (K or Arcturian type), 4,500°C.; orange stars (M or Antarian type), 3,000°C. There are several other classes of stars of very infrequent occurrence. The most notable are the O or Wolf-Rayet type, which are believed to be of abnormally great mass, luminosity, and temperature.

Until recently, the above sequence was believed by the majority of astronomers to represent the order of evolution of the stars as well as of temperature. Bluish-white or white stars such as Rigel or Sirius were considered to be the youngest stars, born from the diffuse gaseous nebulæ, yellow stars such as Capella or the Sun being further contracted under gravitation and at an intermediate stage, while the orange and red stars were believed to be effete suns hastening towards final extinction. The fact that the white stars are observed associated with the nebulæ and that the red stars are seldom or never so placed, was also taken to be confirmation of this order. When it was found from

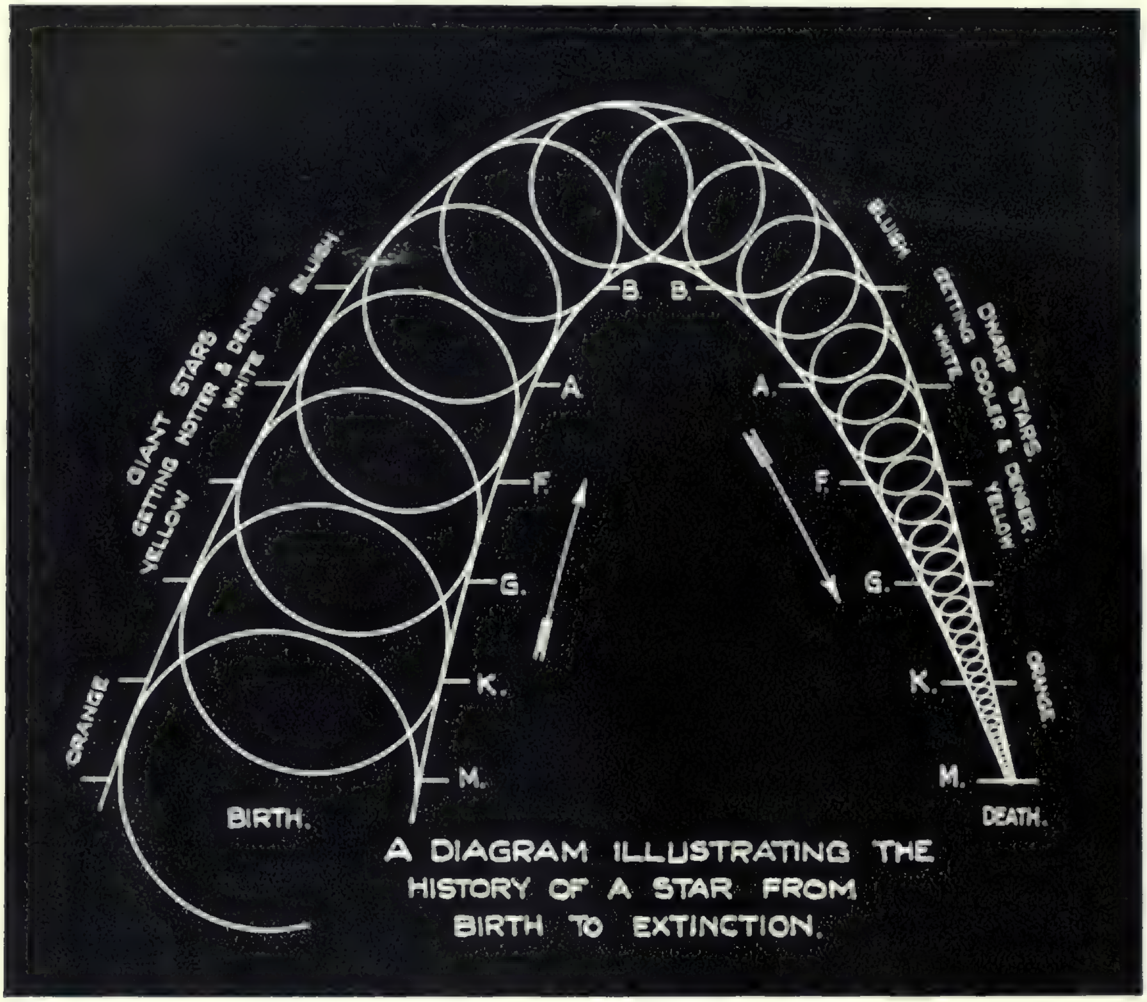


THE GROUPING OF STARS INTO GIANTS AND DWARFS (after CURTIS)

This diagram shows the results of measurements of 2375 stellar distances and brightnesses. The stars are all plotted down for the magnitudes at which each star would shine if placed at a distance corresponding to a light journey of thirty-two and a half years (parallax one-tenth of a second of arc), so that their true relative brightnesses are as shown. The grouping into two branches, one of very bright stars averaging nearly one-hundred times the Sun's luminosity and the other branch of stars diminishing in light with increasing redness of colour, is well brought out. In the diagram the dots and circles indicate the methods by which the parallaxes (on which the absolute magnitudes are based) were determined.

· = modern direct (photographic only). ○ = spectrographic only.

• = direct and spectrographic or hypothetical. ° = hypothetical only.



THE LIFE HISTORY OF A STAR (AFTER LOCKYER).

At birth a star is an enormous sphere of gas considerably less dense than our atmosphere, and shining with an orange-red colour. Increasing density under gravitational contraction is accompanied at first by increase of temperature and change of colour towards yellow-white and bluish-white. When a maximum temperature has been reached further contraction is accompanied by a fall in temperature and progress in colour in the opposite direction towards red. The ratio of diameters at birth and death (as a luminous body) is something like one hundred, and the corresponding density ratio one million.

spectroscopic investigation of velocities in the line of sight that, on the average, speed increased with redness of colour, this sequence of evolution was given an apparent support, although it was not at all clear why velocity should get greater as the stars grew older.

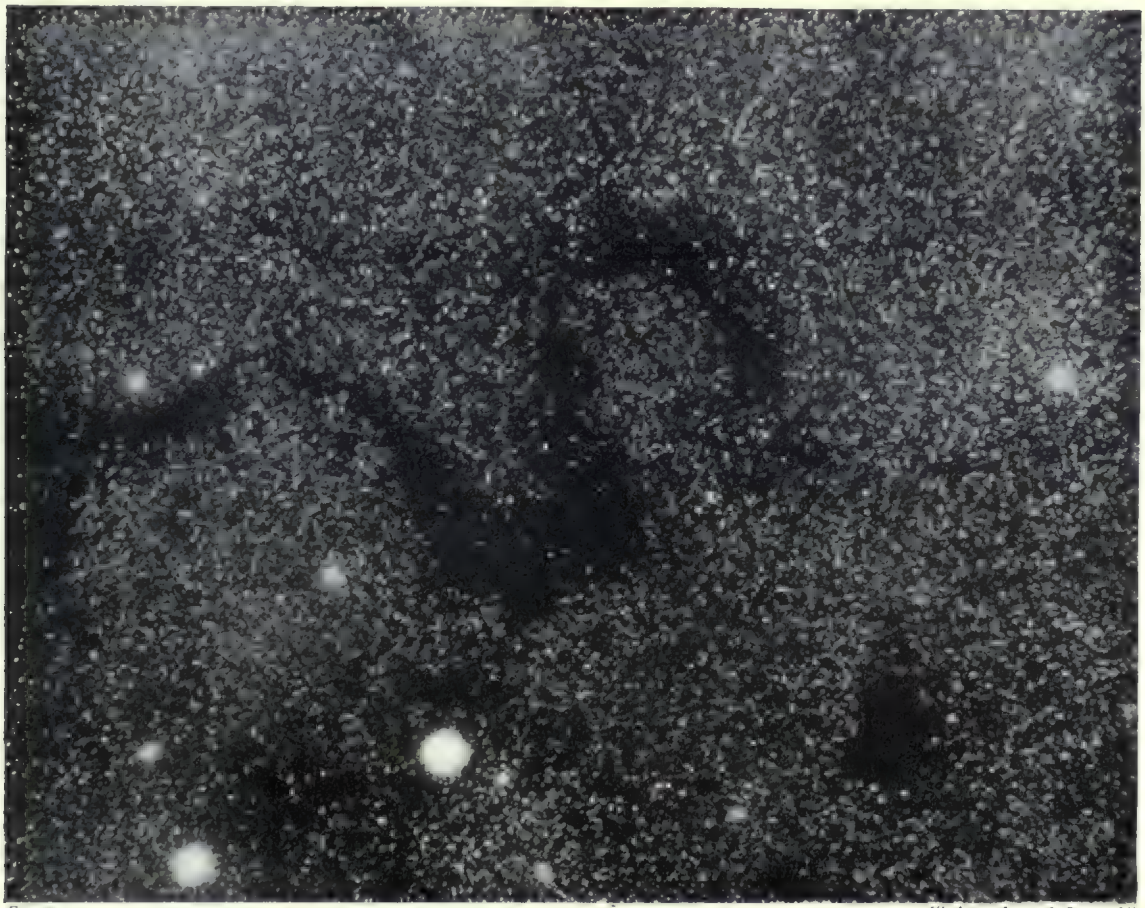
Certain astronomers had, nevertheless, doubted the almost universally accepted ideas on the subject. The red stars had been believed by one or two investigators to be of two types, one increasing in temperature, the other decreasing. Ritter, of Aix-la-Chapelle, had held this view and it was also strenuously advocated for many years by the late Sir Norman Lockyer, who looked upon the yellow stars of G or solar type as also similarly divisible, and considered that the white and bluish-white A and B types were stars in their prime and not the youngest orbs.

These ideas did not meet with much acceptance at the time, largely because they were advocated by Lockyer along with a meteoritic hypothesis of cosmogony, which had otherwise little to recommend it. By this hypothesis an explanation of practically every celestial phenomenon was sought on the assumption that swarms of meteors were concerned. At the beginning of the present century, however, it began to be clear that the true evolutionary order of the stars was probably not that generally

accepted ; and during the past ten years the disentangling of the two series of stars of increasing and decreasing temperature has proceeded apace with the result that the older view has become obsolete.

This conception has been well described as probably the most revolutionary and far-reaching of recent discoveries in stellar physics. The surprising feature of the discovery has been that the first satisfactory demonstration of the true physical grouping of the stars has been due, not to the newer methods of spectroscopy and astrophysics, but to what is usually termed the older astronomy. The lines on which the problem was successfully attacked were chiefly those of parallaxes, the motions of the stars in the sky, the circulating movements of double stars, and the study of variations of light of mutually eclipsing stars. The students of spectroscopy had developed a mistaken hypothesis of evolution, and it was from the older methods of measurement of positions and photometry of variable stars that the solution first came.

In 1905, Professor Hertzsprung, then of Potsdam, pointed out that his studies of the real total brightnesses of the stars, based on measurements of motions and parallaxes, showed that the redder types of stars were divided into two distinct classes, one of great brightness and the other relatively faint. As the spectra were substantially the same in the two groups, his conclusion was that the surface brightnesses per unit of area were similar and that the difference in total luminosity must be due to difference in area of radiating surface, one group being of stars of very large dimensions,



From] [*"Astrophysical Journal."*

OBSCURING CLOUDS IN OPHIUCHUS.

This curious S-shaped marking is of a type at first thought due to vacuities amongst the stars. Further research has shown such dark markings to consist of cosmic clouds, probably of dust and gas. Some astronomers consider them to be possibly the material from which the stars are derived by gravitational concentration.

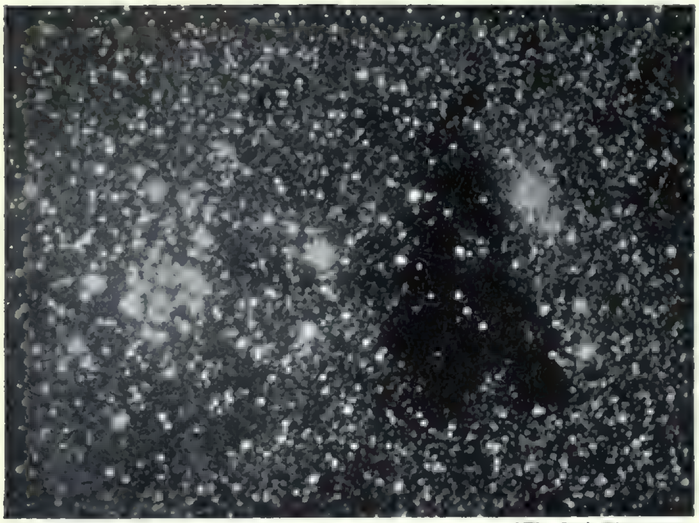


Photo by] [*The Lick Observatory.*

DARK NEBULÆ.

Besides luminous nebulæ, astronomers are now familiar with a class of objects revealed by obscurations of the starry background. First systematically studied by the late Professor Barnard, they seem to be chiefly situated in Milky Way regions.

while the other is composed of considerably smaller bodies. To these two groups he gave the names of " giants " and " dwarfs." Later, Professor H. Norris Russell, of Princeton University, America, independently worked out the same hypothesis, bringing to bear the results of much detailed investigations into stellar distances and motions.

This extraordinary splitting up of the redder spectral types into two distinct divisions, was seen to involve a ratio between the light radiated from a typical red giant to that emitted by a dwarf of the same spectral type, of something like 10,000 to 1. As already indicated, this disparity could only be attributed to dimensions, which would mean that the diameter of the giant would be approximately a hundred times that of the dwarf, or a ratio of volumes of a million to one. There were two extreme assumptions possible : either that the densities of the giants and dwarfs are the same—the masses of the former being then a million times those of the latter ; or that the masses are equal and the density of the giants only one-millionth that of the dwarfs. From knowledge of the masses of stars obtained in the study of the orbits of double stars, there was no doubt that the latter alternative is much closer to the truth. The range of the known masses of the stars is comparatively small. With few exceptions, they are between one-half and five times that of the Sun. At present, the only method of finding the value of stellar masses is by the application of the law of gravity to binary stars, but there is no reason to think that single stars are different in regard to the amount of matter contained in them.

The older theory of evolution from the hot white stars through yellow to red had no place in it for the existence of the two groups of the same spectral type, one of extreme tenuity, often less dense than air, and the other denser than the Sun, which is on the average of the order of a thousand times as dense as our atmosphere at sea level. If all red stars were approaching extinction the reason for this difference in density of the two groups was incomprehensible. Further information was accumulated by study of eclipsing binary stars, for which the dimensions could be found from the shape of the curve of light variation. This information showed that many of the hotter white stars, which were supposed to be younger and less condensed by gravitational shrinkage than the yellower and presumably older stars, were really much the denser bodies.

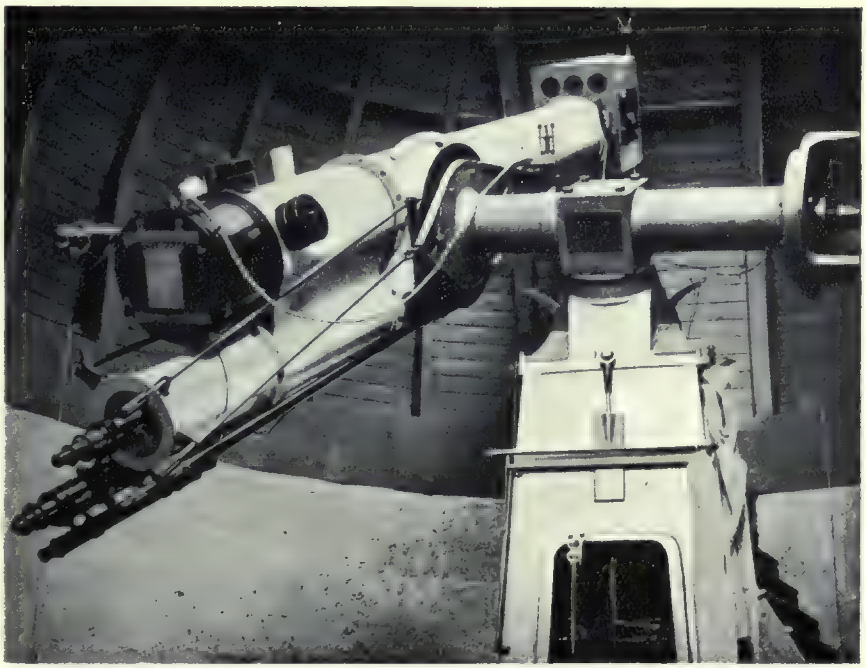
Now it had been demonstrated theoretically by Homer Lane, as far back as 1870, that a mass of gas contracting by gravitation will actually rise in temperature, *i.e.*, will develop heat faster than it radiates it away. If a gaseous star shrinks to half its size, we find that the density becomes eight times as great, while the pressure comes out at sixteen times since the attraction is four times as strong and the weights are borne by a quarter of the area. In such a case the temperature would be twice what it was before. A gaseous star is, so to speak, a " self-heating " body, and big stars with big masses are better in this respect than smaller ones, and will reach higher temperatures. A gaseous star will go on contracting and becoming hotter, its light changing from red to yellow and then to white. This will not proceed indefinitely, however ; when the condensation has gone far enough the material will be too dense to act as a perfect gas and the rise of temperature becomes less rapid,

is checked, and finally a stage of declining temperature sets in. It has been calculated that the greatest temperature will be reached when the density is about two- to four-tenths that of water. Our Sun is about 1·4 times the density of water, has passed its highest temperature and is now in the stage of decline.

In accordance with these considerations, Professor Russell revived the development hypothesis of Lockyer, although with important modifications. The "giant" group, he showed, represents the successive changes in the heating up of the young gaseous stars which are more primitive the redder they are; the dwarf stars are those which have passed their climax of temperature and are now cooling; the redder ones being the most advanced. Taking any level of temperature, with the exception of its maximum, a star will therefore pass through it twice—once "heating" and once "cooling."

When the distance of a star and its apparent brightness are known, it becomes possible to classify it in regard to its real total luminosity—its "candle-power," so to speak. The term "absolute magnitude" is used by astronomers in this connection, and refers to the stellar magnitude which the star would appear to have if placed at a distance corresponding to a parallax of one-tenth of a second of arc. Elsewhere, the gradation of the stars into classes of stellar magnitude is described and at present it is not necessary to refer further to it. When the absolute magnitudes of the stars are grouped or shown graphically on a chart relating the values to the spectral type, it is found that the giants are generally of the same order of brightness, while the dwarfs decrease rapidly in luminosity as they get redder. This is shown on the chart on page 503, on which our Sun is a dwarf star of G type, and about the fifth magnitude. That is to say, if the Sun were removed to such a distance as would involve a parallax of one-tenth of a second of arc and a journey for its light of about thirty-three years' duration, it would shine as a star of the fifth magnitude; not much brighter than the limit of naked-eye vision.

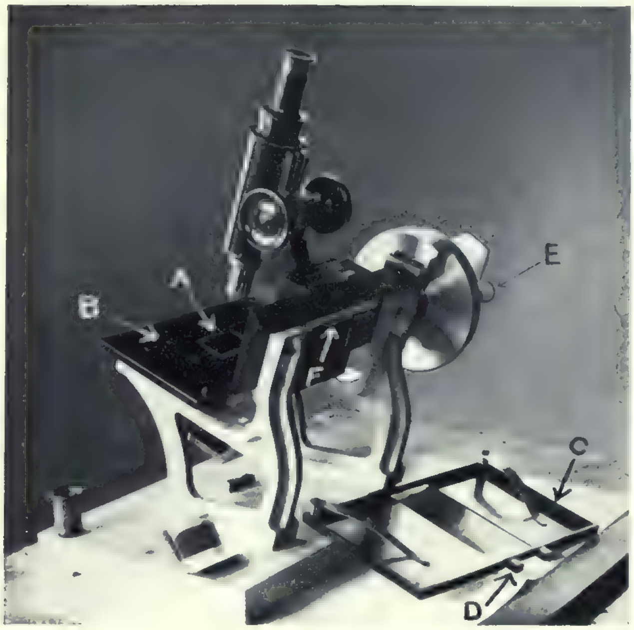
The sameness of luminosity of giant stars, which emit roughly one hundred times as much light as the Sun, is explained by the fact that although a star in this stage of evolution grows hotter and gives an increased output of light per unit of surface it also decreases in surface, and the two factors nearly counteract one another. On the other hand, a dwarf star is both decreasing in intensity of surface brightness and in surface, so that a decline of total light output occurs as it becomes redder and more advanced.



By permission of [*The Director of the N. L. Observatory.*

THE "FRANK McCLEAN" TELESCOPE OF THE NORMAN LOCKYER OBSERVATORY.

This telescope is a "twin," with its components arranged in a manner suggestive of a double-barrelled gun. The upper telescope is a photographic one and is used for photographing the spectra of stars for the determination of "spectroscopic" parallaxes. The spectra are formed by an objective prism (see Chapter I) mounted in a frame before the object-glass. The lower telescope is a visual one and is used chiefly for "guiding" purposes.

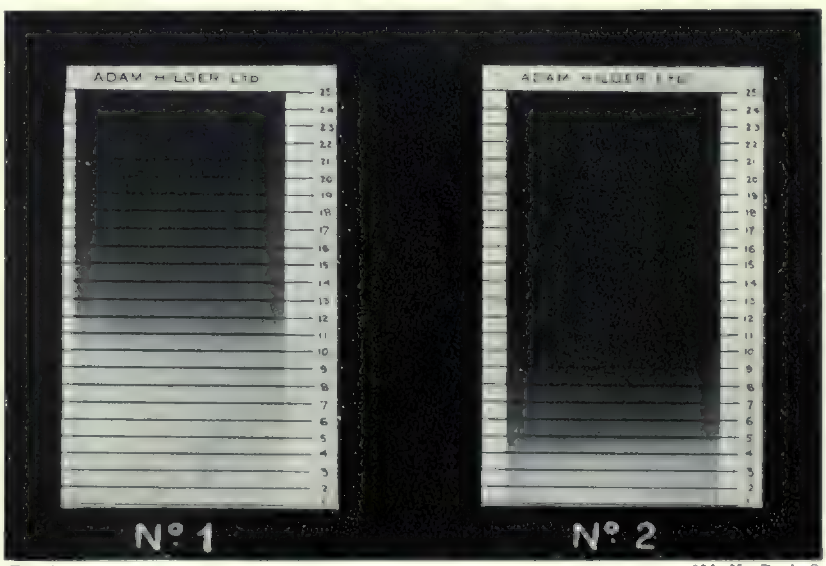


From *M. N., R. A. S.*

APPARATUS FOR CLASSIFYING STARS—
This microscope is used at the Norman Lockyer Observatory, Sidmouth, for the examination of spectra. By a recent discovery connecting the intensity of some spectral lines with the total output of light of a star it is possible to ascertain its luminosity—

It is a remarkable circumstance, and indicative of the complete revolution in the ideas of stellar evolution, that as far as the bulk of stars visible to the naked eye is concerned, the formerly accepted order of development is exactly the reverse of true. This follows from the fact that most of the stars brighter than the sixth magnitude (the limit of unassisted vision) are giants, and evolving in the order red through yellow to white and not from the hotter white stars redward as in the case of dwarf stars. It would be a mistake to suppose, however, that the majority of stars throughout space are giants. The reverse is the case, but the superior brightness of the giants results in their selective preponderance, a greater volume of space being presented to the naked eye in the case of the giants than in the case of the dwarfs.

To summarise the theory now accepted : a star begins its history as a very diffuse red giant of great volume, with a temperature of its atmosphere of about 3,000°C. It contracts by gravitation and grows denser and hotter. The luminosity remains fairly constant at this stage, the shrinking surface counterbalancing the increase in surface brightness. According to its mass it reaches a certain maximum atmospheric temperature and corresponding spectral type. In the case of a star like the Sun, these were probably about 7,500°C. and type F, and for a star like Sirius, which is known to be about two and a half times the Sun's mass, 10,000°C. and type A. A greater mass is necessary to reach the B type, and as large masses are not common, the B type stars are relatively scarce. After the maximum temperature is reached, which probably normally occurs at a density of about two- to four-tenths that of water, a star enters the dwarf cooling stage, when luminosity gradually decreases. Masses less than about one-seventh of the Sun would not be able to reach 3,000°C., and could scarcely be luminous. It is a significant circumstance that no star of such small mass is known.



From *[M. N., R. A. S.*

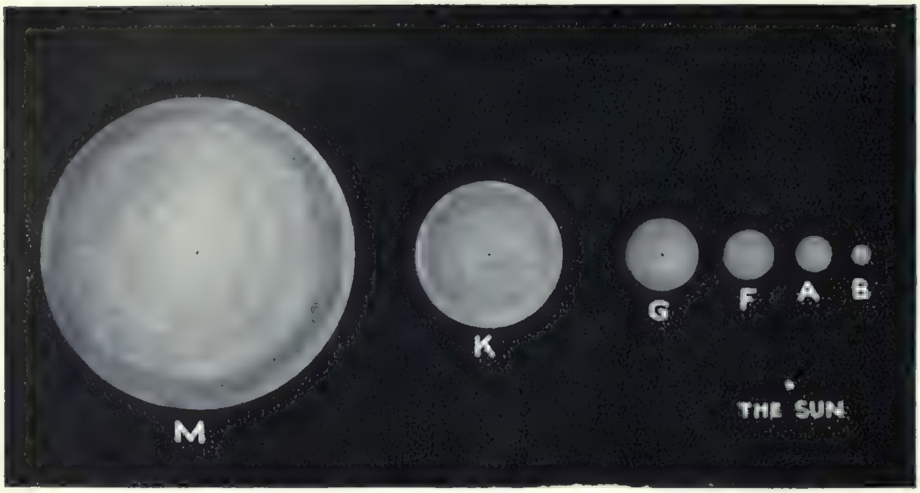
—AS GIANTS AND DWARFS.
—and whether it is a Giant or a Dwarf. The disappearance of the lines when covered by a scale of graduated transparency gives a measure of the intensity of the former, and thus the luminosity of the star investigated.

At first, objections were raised to the giant and dwarf theory on two grounds which have been already mentioned as supporting the older hypothesis. In the case of increase of velocity with greater redness, further investigation has proved that the relationship is really much more one between speed and luminosity or mass than between speed and colour or spectral type. It seems reasonable to expect that in a universe of stars of various masses the effect of their mutual attractions and disturbances would be greater velocities in the smaller masses. Recent studies have shown that the average kinetic energy (or mass multiplied by square of velocity) is about constant in the dwarf classes for the various spectral types, and further research may show the same characteristic for giant stars. This means that the redder type dwarfs, which are the lighter bodies, move more rapidly on the average than the whiter dwarfs. The other ground for objection was found in the circumstance that young red giants are seldom if ever observed near the gaseous nebulæ, while the hot white stars are commonly associated with these objects. Recent work has shown, however, that the luminosity of the gaseous nebulæ is probably due to reflection or excitation from the light of the included B type stars, and that such nebulæ are more likely to be the ejected products of the stars than the material from which they are born. It seems probable that the "star stuff" from which the early diffuse giants are produced, is to be found in the dark cosmic clouds composed of dust particles and gas which reveal their presence by obscuration of the starry background in many parts of the sky. The absence of young diffuse red giants in a stage prior to M type is explained by Russell as probably due to the speed through which this stage is passed. As will be seen later, it is likely that such stars would run through that part of their career so quickly that there would be very few of them in a given volume of space at any one time, and their rarity would then be accounted for.

THE GIANT STARS.

By a wonderful adaptation of the principle of light interference, the astronomers at the Mount Wilson Observatory, California, have been able to measure the angular diameters of some of the giant stars. The distances being approximately known, their true diameters can be calculated. The diagram shows about the relative sizes for five giants, the Sun's disc on the same scale being about one one-hundred-and-twentieth part of an inch—smaller than the dot over this letter i !

Confirmation of the substantial accuracy of the giant and dwarf grouping of the stars has lately been received from two quarters—the spectroscope and the interferometer. By measurement of the intensity of the lines of certain elements in stellar spectra it has been found possible to ascertain



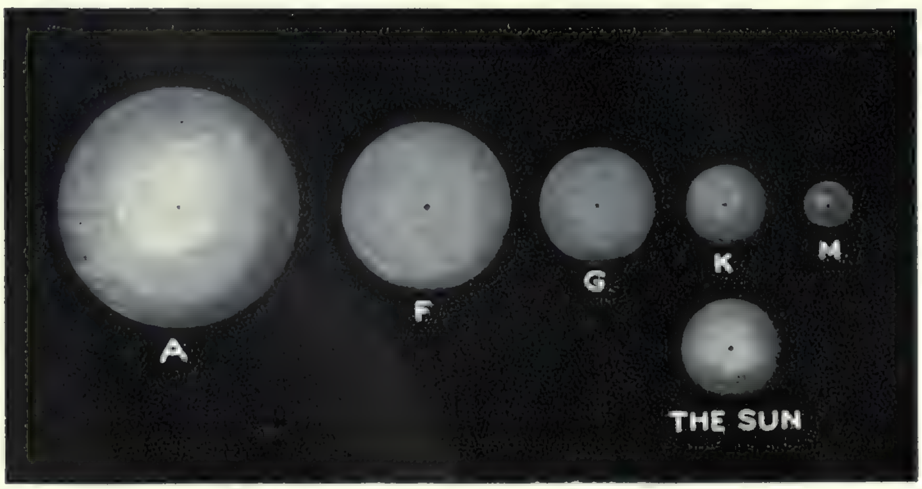
TYPICAL GIANT STAR DIAMETERS.

The relative sizes of the typical giant star of the various spectral types is shown above. The progressive contraction, which occurs as a star gets older, denser and hotter in the giant stage, is probably represented fairly well by the diagram, but may actually be somewhat greater.

the absolute magnitudes of large numbers of stars. A powerful means of finding distances is thus provided, as, knowing the apparent brightness and the real total output of light (absolute magnitude), parallaxes can be simply calculated. The observed differences in the intensities of certain lines in stars of the same spectral type, but different luminosities, seem to be due to the smaller force of gravity and consequent lower atmospheric density at the surface of the diffuse giants, which at stellar temperatures results in atomic changes called ionization. Certain elements are very sensitive to these changes and the giants and dwarfs show considerable differences in the spectral lines concerned.

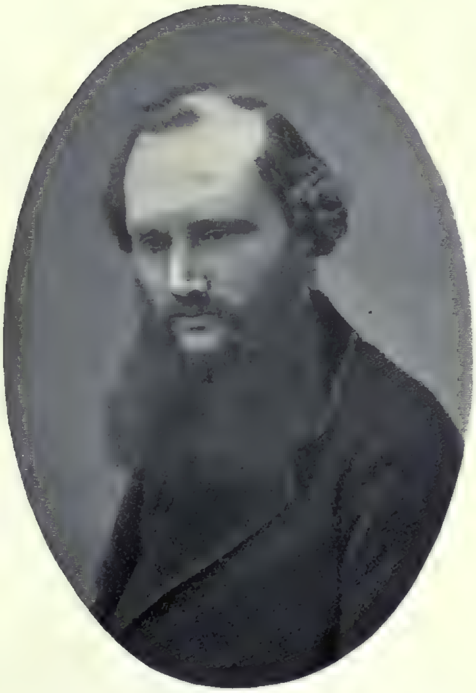
By measurement of the intensities of these lines in the spectra of stars of known parallax and absolute magnitude, a scale is provided for use with stars for which such information is required. This method is chiefly due to Professor Adams, of the Mount Wilson Observatory, California. It is now being exploited in several observatories throughout the world. At first it was only applied to the yellow and red stars, but it is now being employed with some success to the white stars (B and A type), in which the lines are more diffuse and difficult to measure.

In the first chapter the interferometer as used at Mount Wilson with the 100-inch telescope has been described. By its aid the diameters of several "super-giant" stars have been ascertained. These are: Antares (about 360 million miles), Betelgeuse (not less than 200 million miles), β Pegasi (at least 75 million miles), Aldebaran (about 40 million miles), and Arcturus (about 30 million miles). The first three are of M type



TYPICAL DWARF STAR DIAMETERS.

The relative diameters of the dwarf stars of most frequent occurrence, is shown in comparison with the Sun, which is itself a G-type dwarf. The contraction in this stage is accompanied by cooling and is probably somewhat less than is indicated by the progression of diameter in the diagram. The letters refer to the spectral types.



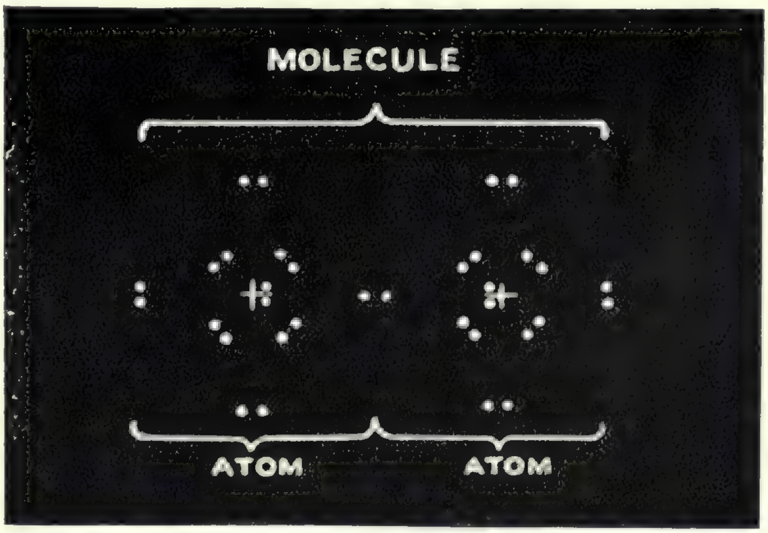
LORD KELVIN.
The profound mathematical and physical studies of this celebrated scientist led to ideas of the age of the Sun and stars which have now been replaced by more modern discoveries.

and the two others are K stars. All are probably more massive than the Sun, perhaps fifty times as great, but their densities are certainly very slight, comparable with or more tenuous than air. A graphic illustration intended as an attempt to convey to the mind the enormous proportions of Betelgeuse, will be found on page 23.

The diameters of the typical star of the various spectral classes have been calculated to be approximately as follows, using the Sun as the unit: Giants; M, 65; K, 30; G, 15; F, 10; A, 7; B, 5: and dwarfs; A, 2·5; F, 1·8; G, 1·2; K, 0·8; M, 0·5. It will be seen that the Sun (G type) is rather smaller in diameter than the normal dwarf of its class. Its mass is normal, however, and the density therefore greater than usual.

At first sight it might appear impossible to find out anything about the conditions in the interior of a star. Direct study is confined to spectroscopic scrutiny of surface conditions from which we derive some knowledge of the temperatures and compositions of stellar atmospheres. It is here that the physicist joins forces with the astronomer, and by the labours of a brilliant group of mathematical physicists such as Eddington, Jeans and Aston in England, and Russell and others abroad, something has been done to penetrate into the inside of the stars. In what follows, the conclusions of Eddington will be those mainly described.

Elasticity in a gas is familiar to all who have had to deal with a pneumatic tyre. This property is the result of the energy of motion of the molecules of gas hastening in all directions and trying to spread apart. The higher the temperature the faster these motions are, and the greater the expansive force. Inside a gaseous star there is a condition of balance, the weight of the layers above pressing down and the elasticity of the gas from its molecular motions trying to move the upper layers outwards. As there is equilibrium which apparently lasts for hundreds of years, judging by the constancy of the light of most of the stars, we must conclude that there is exact internal balance, and from this fact we



THE CONSTITUTION OF AN ATOM.
Astronomers' problems are concerned with the infinitely small as well as with the infinitely great. The study of stellar interiors involves the theories of the atomic structure of matter. The illustration shows a molecule of an element (chlorine) composed at normal temperatures and pressures of two atoms. The crosses are the atomic nuclei, the dots are the electrons. At temperatures of over 2,000°C. the two connecting central electrons separate and we have then a monatomic condition. At higher temperatures first the outer ring and then the inner ring of electrons are stripped off, the final state in the interior of a star being free nuclei and electrons moving about at great speeds.

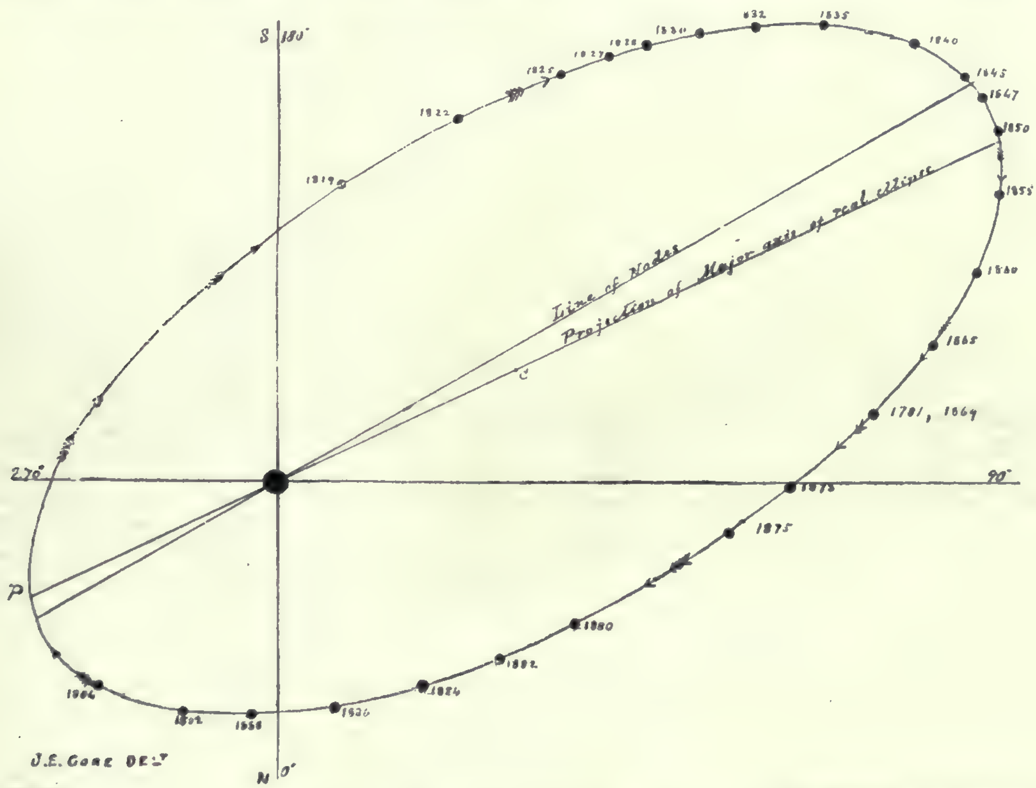
must reason in estimating the internal temperatures. At the centre of a star this varies in the different types from about two million to twenty million degrees. This means that the atoms are rushing about at very high speeds, up to one hundred miles per second, which, however, is a comparatively small rate for atomic speeds. Each atom is being continually pulled inwards by gravitation, and is all the time thrown out again as the result of collisions with other atoms. The store of heat

SOME MULTIPLE STELLAR SYSTEMS AS SEEN IN POWERFUL ASTRONOMICAL TELESCOPES.
In each system the stars are physically connected and revolving in mutually disturbed orbits round their common centres of gravity in long periods of years. The scales of the drawings are not the same.

possessed by the star is composed largely of these motions, but there is another store—the ætherial heat. This is made up of waves in the æther similar to, but smaller than, those of light. Æther waves are given different names according to their length from crest to crest. The long ones used in wireless telegraphy are called Hertzian waves ; then come the invisible heat waves ; then the waves which give the sensation of light ; then photographic light waves. A still shorter type are the

X-rays used in medical work. The æther waves inside a star are similar to the X-rays. It is only at the enormous temperatures of the stars that this portion of the store of heat possessed by a heated body becomes appreciable. In bodies raised to the highest temperatures possible in our terrestrial laboratories, the ætherial part is insignificant, but it becomes very important in the case of the stars. This is due to the fact that waves in the æther exert a pressure on any obstructing object. Inside a star the intense ætherial energy acts like a distending wind, counteracting gravity and tending to disrupt the star.

In modern physical science, knowledge has now advanced to the stage that a mathematical physicist can, without astronomical information, calculate the relative proportion of heat in the stars due to atomic motions and ætherial waves. He can also calculate the ratios of inward gravi-



From] ["*The Scenery of the Heavens.*"

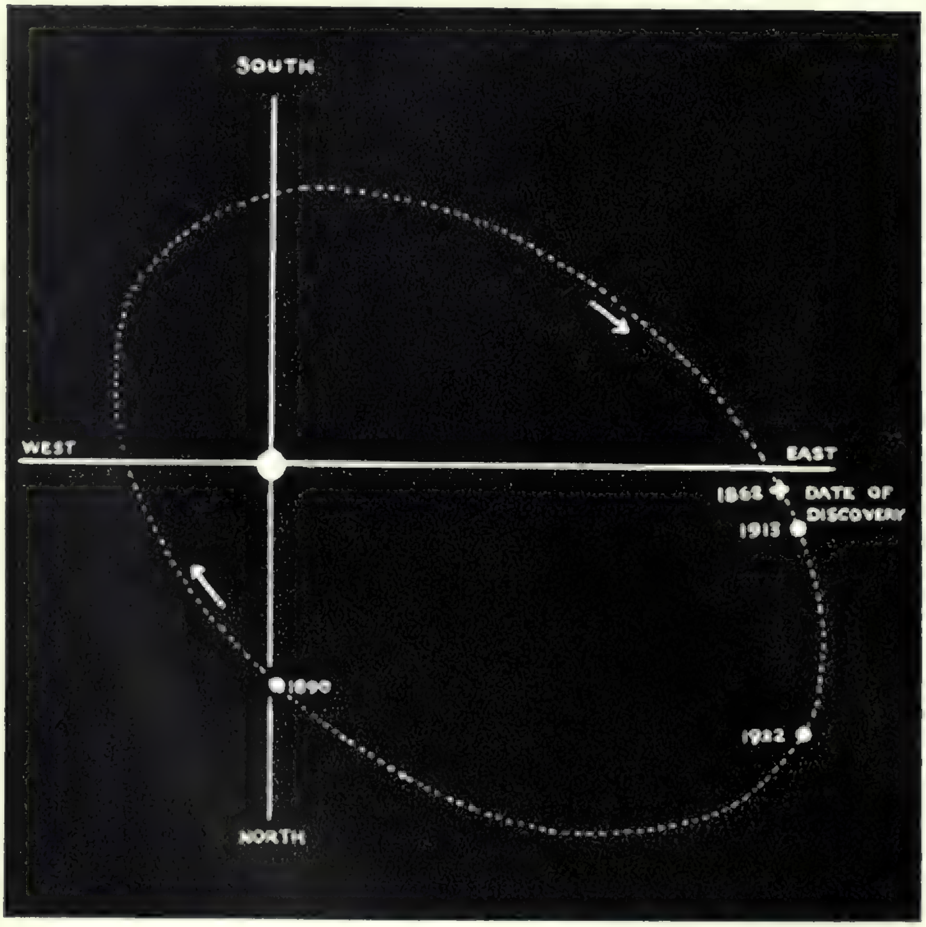
THE ORBIT OF A DOUBLE STAR (70 OPHIUCHI).

The diagram shows the "line of nodes," which connects the points at which the orbit plane intersects a plane at right angles to the line of sight, and also the position of the major axis of the true ellipse. The companion is now placed nearly as in 1840.

tational pressure to outward pressure of ætherial waves. When this is done it is found that the fraction of weight of stellar material supported by the ætherial pressure becomes greater with increase in mass of the star considered. At a certain order of mass there would be a tendency to disruption from this cause, assisted by the effect of the centrifugal force of the star's rotation. The critical mass found by these physical calculations is that which is observed to be commonest among the stars ; the conclusions of the physicist are closely in accord with what is found by the astronomer. Gravitation is the force which draws matter together. If there were no counteracting forces there would be no limit to the size of a star, except available amount of material. Against gravitation we have ætherial pressure and centrifugal force, and throughout the universe, as far as we have been able to ascertain stellar masses, the gravitational aggregation seems to have proceeded just as far,

on the whole, as the opposing forces would permit. So far the inside of a star has been visualised as a concourse of moving atoms and ætherial waves. There is another class of inhabitant, however—free "electrons"—which have broken loose from the atoms at the high temperatures, and are moving at much higher speeds than the atoms themselves.

An atom of an element is like a miniature solar system; a composite central nucleus carrying positive charges of electricity round which revolve in circular and elliptic orbits a number of satellite electrons of negative electricity. The number of satellites varies for each element from one to ninety-two, and very many of these satellites must have become detached in the interior of a star. Generally, at least half have broken loose so that the average molecular weight of the material is very much less than it would otherwise be, and also much more uniform. Given a volume of gas of known mass and with its material thus simplified the modern physicist, again without the assistance of astronomy, can calculate how brightly it would shine as a star. Indeed, the problem is very largely one of accounting for the slowness at which the enormous energy produced is radiated. This slow rate is found to be due to the great opacity of the star's substance to the very short ætherial waves. Although the rarity of a giant star is so very great, a small thickness of its material is sufficient to obstruct a large proportion of the energy. The Earth's atmosphere is itself more opaque to ordinary light waves than is commonly realised; about one-fifth of the light from celestial objects is scattered or sent back to space, but to the X-ray type of radiation the gaseous interior of a star is so obstructive that, with the same density as air, a layer only six inches thick would be almost an impassable barrier. The consequence is that the loss of energy by radiation from a star is very slow in relation to the

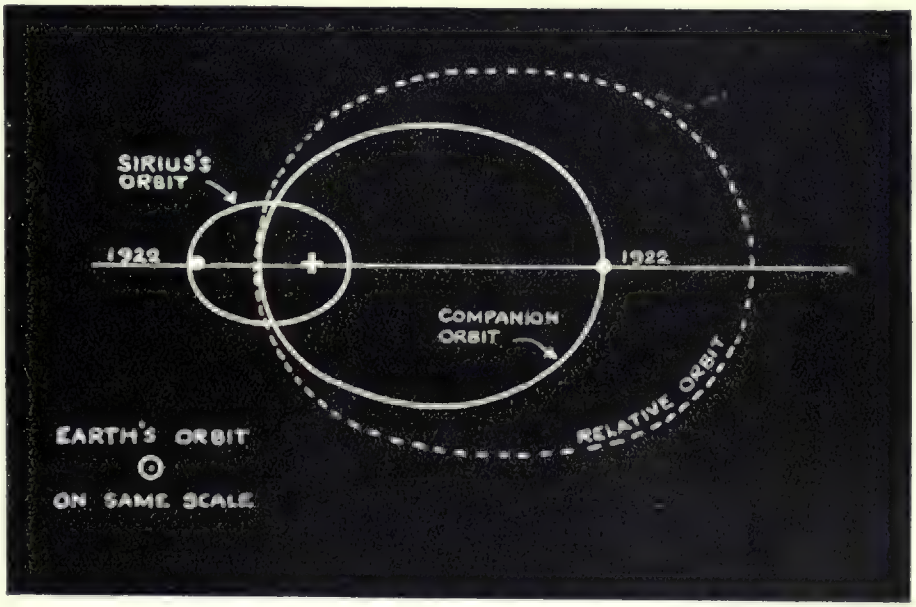


THE APPARENT ORBIT OF THE COMPANION OF SIRIUS.

From irregularities in the motion of Sirius across the sky, the existence of a companion whose gravitational disturbance was believed to be the cause, was predicted in 1844. The companion was discovered in 1862, since when it has performed more than a complete revolution round the primary, the period being about fifty years. Its quicker motion when near the primary will be seen from the fact that more than half the orbit was traversed in the twenty-three years from 1890 to 1913. It is now moving at about its slowest orbital speed.

amount contained. The luminosities calculated for the stars by the mathematical physicist, entirely from data provided by laboratory research, are found to agree well with those obtained by the methods of the astronomer.

The study of the internal conditions and radiation of a star introduces inevitably the question: What is the source of the light and heat which is so copiously emitted by the Sun and stars? Until lately the answer generally given was that it is obtained from the inward fall of the material due to contraction under gravitation. Lord Kelvin showed that this hypothesis, originally propounded by the German physicist Helmholtz, led to an age for the Sun of something like twenty million years. The results of the work of geologists in regard to the age of the Earth, based on study of the rock formations and on other considerations, are much opposed to this time-scale, which is now considered too short. Eddington has calculated that a star, not much larger than the Sun probably was in its giant stage, would radiate away as much energy in a hundred thousand years as would at present suffice to maintain our luminary for ten million years. On the contraction hypothesis, the evolution through the whole of the giant stage would be very rapid. In about eighteen thousand years a typical M giant would pass to type G, and in eighty thousand years it would have reached its highest temperature and be about to start on its downward path. As previously mentioned, most of the naked-eye stars are in the giant stage. We cannot believe that all these stars were formed in the past eighty thousand years.

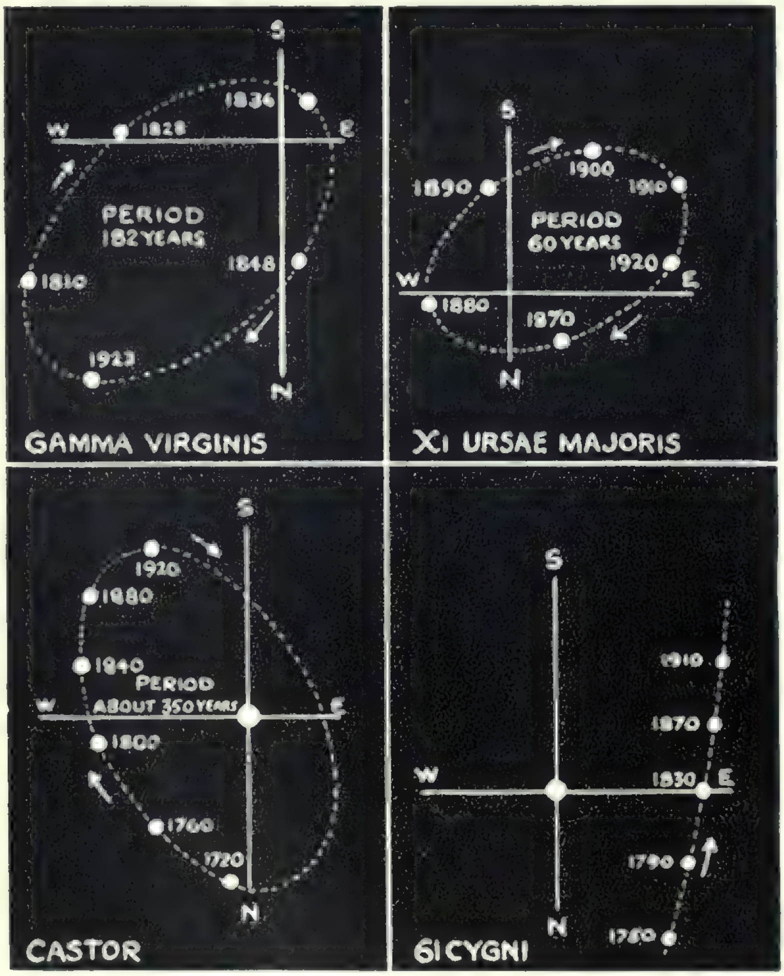


THE TRUE ORBITS OF SIRIUS AND HIS COMPANION.

This diagram shows the true shape of the paths, which are completed in about fifty years. The smallest ellipse is that of Sirius itself. The dotted ellipse is the true shape of the relative path, if Sirius be assumed stationary. The relative sizes of the stellar orbits and the Earth's orbit will be gathered from the small circle showing the latter. The cross marks the centre of gravity of the system.

From more than one department of knowledge the duration suggested for a star's life is much greater than previously thought. For example, the American mathematician, F. R. Moulton, has made an attack on the problem from considerations of the constitution of the globular clusters of stars. Their symmetrical distribution implies a long dynamic evolution which has resulted from the mutual gravitational action of the stars in their approaches to each other. The period required for a single circuit of a star through the cluster is estimated at something like a million years. Moulton finds that, on the average, a star would make several thousand revolutions before it would pass near enough to some other star to change its direction of motion sufficiently to influence the symmetry of the cluster of which it is a member. He consequently infers an age for the stars of several thousand million years. This order of magnitude is also suggested from the age derived for the Earth by the geologists and physicists, and it has become plain that there must be some other source of stellar energy besides gravitation. This source is believed to be the energy of the atoms of matter themselves. There seem to be two alternatives—one that the simpler chemical elements are being changed into

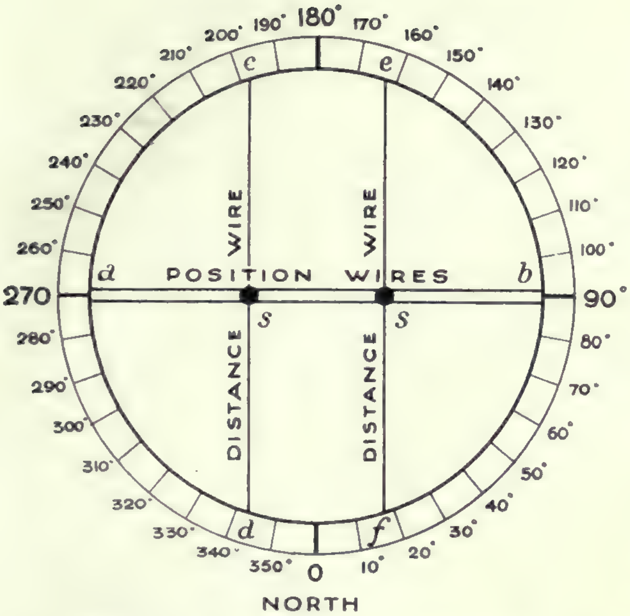
those of more complex atomic structure, energy being set free in the process, the other that matter is being destroyed as such and transformed into the energy of which it is thought all the elements are constituted. Physicists have discovered that in transmuting helium into hydrogen, a small fraction of the mass disappears and takes the form of ætherial waves of energy. Such a transformation in a star of which only five per cent. was hydrogen, would provide sufficient radiative energy, as a first step in the formation of the more complex atoms. This liberation of energy would not occur at the outset when the interior temperatures were not high enough. Stars in the very earliest state of evolution, prior even to M type, would thus be radiating solely as a result of gravitational contraction and would run through their course with great rapidity. On this hypothesis their apparent absence from the sky is understandable.



ORBITS OF DOUBLE STARS.
The apparent orbits of four connected pairs of stars are shown. The periods of revolution are well known for the shortest, but become increasingly uncertain for the longer ones, as only a part of the circuit has been observed since the date when telescopic power became great enough to show them as double stars.

Some stars of abnormally large luminosity or of mass twenty to eighty times the Sun are known. These are explained by Eddington as possibly having been formed in regions of space in which the element hydrogen is present in greater abundance than usual. Admixture of this, the lightest, element reduces the average atomic weight. Outward radiation pressure is then less than with higher average atomic weight and gravitation gets a better chance to aggregate large masses.

We have hitherto been dealing with the individual single star. The sky contains, however, very many connected systems of double and multiple stars, and indeed, some authorities consider that the single star may be the exception rather than the rule. The first double stars were discovered by accident by the users of the telescope. They were thought to be simply two stars seen nearly in the same line of sight, not physically connected, and probably very distant from each other—especially when there was considerable difference in their brightnesses. Their observation was at first made in the hope that the measurement of the apparent angular distances apart might lead to a determination of stellar parallax, the supposedly nearer one having a greater apparent displacement, due to the Earth's orbital motion, than the other component. Sir William Herschel catalogued a great number, at first with the idea of determining parallax in this way. In the year 1767 the Rev. John Michell

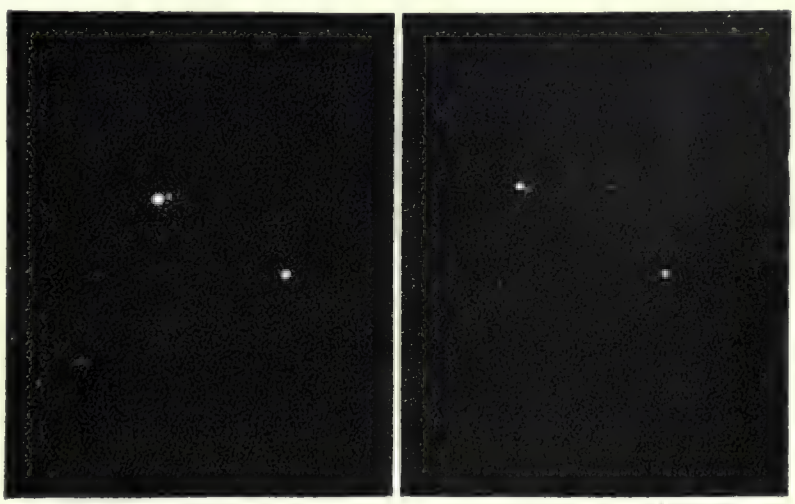


METHOD OF MEASURING A DOUBLE STAR.

Two pairs of spider lines, or "wires," at right angles to one another are seen in the field of view of a micrometer. One pair consists of two movable wires (*c d* and *e f* above), which can each be adjusted to pass through one of the components of the double star. The amount of their separation is then read on the divided drum used to move them. The remaining pair, *a b*, is adjusted to the direction of the line joining the stars, as shown above. The reading of a divided circle outside the eyepiece then gives a measure of the angle made with the meridian by this line. In this case the "position-angle" is 90° (or 270°).

showed by the theory of probabilities that these pairs were extremely likely to turn out to be connected physically and later Herschel proved that this was so from observations separated by a sufficient interval of time. Thus, a considerable time after they were known in comparatively large numbers, their true nature became apparent, and they were studied in regard to their motions about each other, their observation for parallax being abandoned.

The efforts of modern observers have provided the information that at least one star in eighteen appears in the most powerful telescopes as a close double, and there is no doubt that the great majority of them are connected and in mutual revolution under their gravitational attraction. An increase is observed in the numbers with greater degree of closeness of components, which is so marked as to lead us to believe that those systems with smaller orbital dimensions are really the more numerous. Actual orbits have been computed for about 150 binary pairs from telescopic measurements of their changing relative positions. When the particulars of an orbit and the parallax are known, the total mass of the pair in terms of the Sun's can be easily calculated. This varies with spectral type. In systems composed of giant stars the values are mostly comprised between seven and twelve times the Sun, and in dwarf pairs from about five to six in the white stars down to 0·7 or 1·0 in the redder classes. The greater average values for the whiter pairs seem attributable to the greater mass necessary to reach the higher luminosities of the whiter and hotter types.



E. E. Barnard.

PHOTOGRAPHS OF A BINARY STAR (KRÜGER 60).

The relative movement of the two stars after the lapse of seven years is shown, a revolution being completed in fifty years. The third star to the right is not connected with the pair and lies very much farther away.

By the relative displacements in their orbits, it has been found that, generally speaking, the fainter components are the less massive. It has also been discovered from differences of spectral type and colour of the separate components of connected pairs, that the fainter

(and less massive) star seems to be almost invariably the farther advanced in its career. In the case of pairs which are giants, the brighter one is the redder and therefore younger, star; in dwarf systems the fainter is the redder and therefore more advanced. As their birth is presumably contemporaneous, this points to more rapid aging in smaller masses.

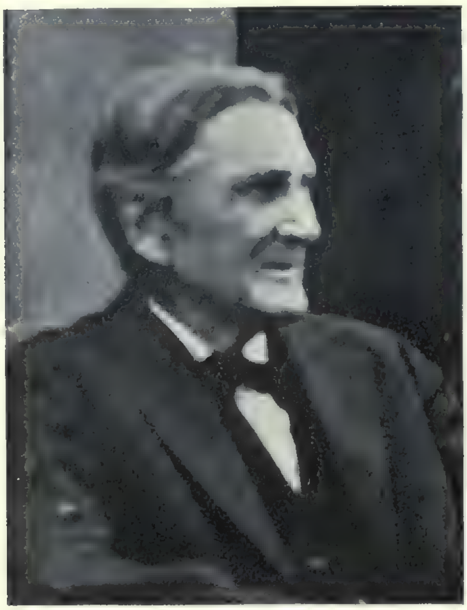
Several hundred stars are known to consist of two or more components revolving so closely together as to be inseparable by ordinary telescopic means, but revealed by the periodic displacements or duplications of the lines in their spectra. Generally, the periods of revolution are much shorter than in the case of those binaries visible as such in the telescope. The range covering both classes together goes from less than a day up to hundreds of years, but there is a gap between the longest periods of the "spectroscopic binaries" and the shortest of the "visual binaries." This is attributable to the circumstance that the displacement of spectral lines in the slower moving pairs of moderate periods of revolution is too small to be noticeable, while the stars themselves are nevertheless too close for separate visual observation. Spectroscopic pairs are most numerous among the whiter stars (B and A type) which comprise nearly sixty per cent. of those known. They are chiefly stars visible to the naked eye, which for the most part are giants probably of high mass on the average, and to this circumstance we may possibly attribute the extremely high proportion of stars which have been found to be double by the spectroscope—about one in every three or four of those examined in this way. As Professor Aitken, of the Lick Observatory, a great authority on binary stars, states: "We do not yet know whether that proportion will hold among the fainter stars, but on the evidence before us we may venture the suggestion that perhaps the stars of larger mass, and hence presumably greater luminosity, are the ones which have developed into binary systems."

The periods of revolution are generally shorter on the average in the hotter white pairs, which may be, in part, due to larger mass, revolution being faster owing to greater gravitational attraction. The mass of a spectroscopic binary can only be determined in any particular system if the inclination of the plane of its orbit to the line of sight is known. This is the case only when the stars eclipse each other as in "Algol" stars, so called

From Bryant's "A History of Astronomy." [*By permission of Messrs. Methuen & Co., Ltd.*

WILHELM STRUVE (1793–1864).

Struve's accurate observations of some three thousand double stars, early in the Nineteenth Century, laid the foundations of our present-day knowledge of these systems. William Herschel had previously given much attention to this branch of study, but his instruments were unsuited to the precise and delicate measurements required.



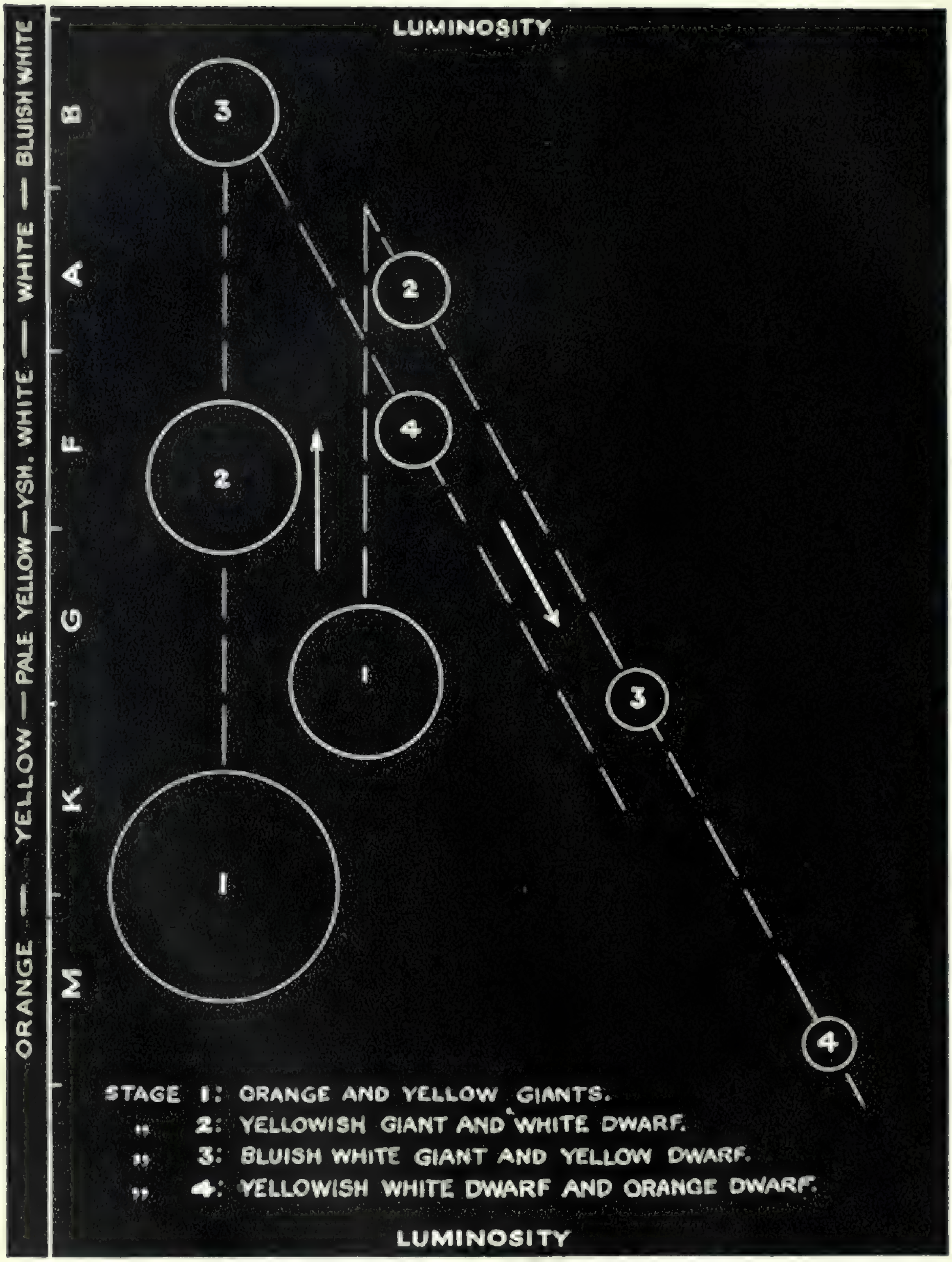
From] ["*Popular Astronomy.*"

SHERBURNE WESLEY BURNHAM.

Burnham is famous as one of the most successful discoverers and observers of double stars of recent times. He possessed a remarkably acute eye and was able to take full advantage of the fine instruments with which he worked. For many years he had the use of the Forty-inch Yerkes refractor, with which he discovered some of the closest visual binaries known to us.

DOUBLE STAR COLOURS.

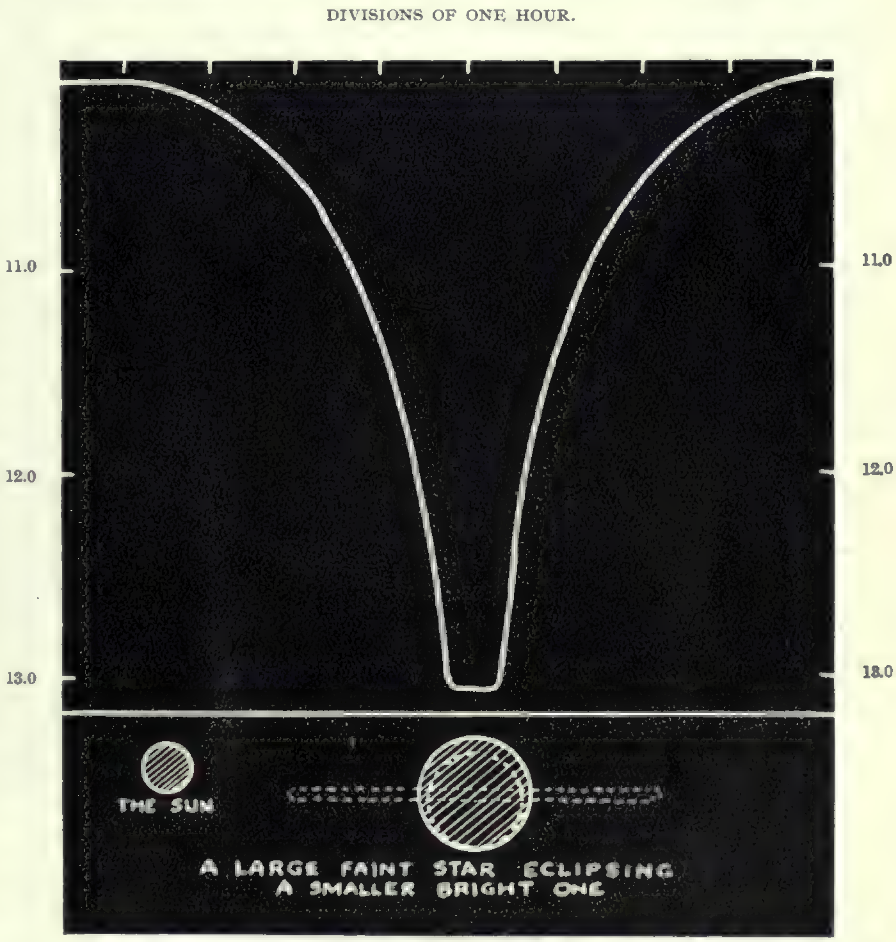
The three pairs in the top row are all dwarf stars, the bottom row being systems in which the primary at least is a giant. The secondaries of the former are all redder than their primaries, while in the latter they are bluer. The colours of double stars as seen in the telescope are often subject to physiological effects which appear to make the colour contrasts somewhat unreal, although very beautiful.



THE PROBABLE EVOLUTION OF A DOUBLE STAR.

The more massive and brighter component of a binary system probably develops more slowly than the fainter component. It thus results that the colours of the latter are generally *bluer* than those of the primary stars in the giant stage, and *redder* in the dwarf stage of development.

after the variable star of that name. Average values of mass corresponding to average angles of inclination can be estimated, however; and when these are classified according to spectral type the whiter types are found to be decidedly the more massive on the average, just as in the case of visual binaries. If the spectra of both components can be discerned, which is the case when the light of the brighter is not relatively so great as to drown the spectrum of the other, the relative displacements or "doublings" of the lines enable the ratio of the masses to be found. In such cases it has been ascertained that, almost without exception, the fainter bodies are the less massive.



AN ECLIPSING VARIABLE STAR.

This shows the curve of change of light for Y Leonis, a binary system consisting of a bright star nearly twice, and a fainter one about two-and-a-quarter times, the Sun's diameter. When the fainter star comes between the brighter one and the Earth, at intervals of forty-and-a-half hours, there is an eclipse and a drop of nearly three magnitudes in the apparent light of the star. Astronomers cannot see the two components but by a study of the shape of the light curve they can deduce their sizes. When the spectrum is known, the real light output can be calculated and the distance derived. In this case it is about 3,000 light-years!

About two hundred eclipsing binaries, which vary in their light as a consequence, are known. From their curves of light variation it has been possible to derive considerable information in regard to orbits, surface brightnesses, and actual dimensions of the individual components. The fainter star is always found to be self-luminous and usually redder than the other when its colour can be observed during eclipse of the brighter component.

The majority of known eclipsing and spectroscopic binaries belong to the whiter and hotter types. The components of the former are, however, mostly of the grade of luminosity (*i.e.*, total light output) associated with dwarf stars; the spectroscopic binaries are, as already stated, mostly giants. The fainter components of eclipsing pairs are usually larger in diameter than their brighter companions, having as a consequence smaller densities; in the wider visual pairs the reverse seems to hold. The difference may be explicable on one or both of two grounds. The first is the greater chance that stars with companions of abnormal development and unusually great dimensions will be observed as eclipsing variable stars; the second is the possibility that close binaries of the eclipsing and spectroscopic type may be different in their mode of origin from the visual or more widely spaced pairs.

With regard to the birth of binary and multiple systems, there are three theories commonly

advanced. One is that a chance encounter of two or more stars has resulted in their revolution about each other. This is called the " Capture Theory." The second is that condensation has occurred about independent nuclei in a gas or dust cloud, or nebula, and the third that a rotating single star has divided into two or more components by centrifugal or tidal fission reinforced by internal radiation pressure.

The first of these methods does not seem likely to have been frequent, taking into account the enormous distances which separate the stars from each other. Calculations show that in ten thousand million years only about one star in three will be approached by another within a radius of seven times the distance between Neptune and the Sun. Another strong argument against the Capture Theory is to be found in the relations of the spectra and colours of double stars previously mentioned, which show that the fainter components are evidently the more advanced in their career. This could not be expected to be a general rule if the origin of pairs were by capture, unless simultaneous origin is attributed to stars occupying what seems an improbably great volume of space.

H. E. Mathews.

THE LICK OBSERVATORY, MOUNT HAMILTON, CALIFORNIA.

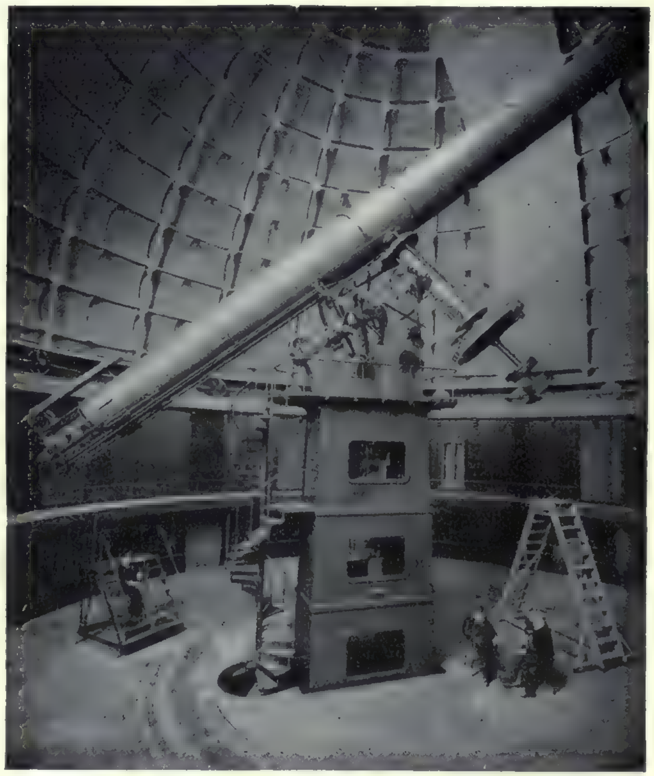
This famous institution was founded and endowed over thirty years ago by an American millionaire, the late James Lick. It is situated in a favourable climate, at over 4,000 feet elevation, and the skilful use of its powerful instruments has resulted in considerable advances in knowledge.

The second and third methods of origin above referred to seem to be both valid, and may be the normal ones for the relatively widely-spaced visual pairs and for the close spectroscopic and eclipsing binaries, respectively. In the case of origin from independent nuclei, the evolutionary process would appear to be somewhat as follows :—In the parent nebula there would be here and there parts of greater density, which would act as centres of attraction. At first the growth of these centres would be slow, owing to comparative feebleness of gravitational action. More rapid development would occur as the masses of these nuclei increased and while the nebular material was still plentiful ; later, when material was nearing exhaustion, the growth would again become slower. Slow rotations would be set up by original motions or by inrushing material which did not strike the nuclei centrally, and this rotation would become more rapid as contraction resulted from the radiation of the heat produced in the process of accretion. The assumption of spherical forms would mark the first stage of stellar life, two giant stars, revolving round their common centre of gravity, appearing where the denser parts of the original nebula had been situated.

The fission theory has been developed by mathematicians such as Sir George Darwin, Poincaré, and Jeans. It would appear very probable that the closer double stars have originated in this way.

As a result of this process of division of a rotating single star, it would not be astonishing to find the companions to be less dense than their primaries (although further advanced in spectral type and colour) as they would possibly be composed of the outer and more tenuous layers of the parent body. In about ninety eclipsing binaries, for instance, four out of five are thought to have a companion less dense than their primaries, although more advanced in development as judged by spectral type. On the other hand, the wider visual binaries, presumably evolved from independent nuclei, are likely to have their secondaries more advanced and denser than their primaries, being probably of independent, though simultaneous, origin.

One well-marked feature in the orbits of double stars should be referred to. In the closest and most rapidly revolving pairs the orbits are generally almost circular, a more oval or eccentric elliptical form characterising the orbits of wider and slower moving binaries. Theoretical considerations show that close pairs can become wider pairs by the effect of the tides set up in the bodies of each star, but not sufficiently so to cause those like spectroscopic or eclipsing binaries to become separated to the distances common in visual double stars. Tidal forces may be responsible for the observed departure from circularity towards ovalness in the orbits of the two groups, one of which contains pairs originating by fission of single stars and the other is composed of binaries developed from adjacent nuclei in a parent nebula.



THIRTY-SIX-INCH REFRACTOR OF THE LICK OBSERVATORY.
This magnificent instrument has for over thirty years been employed chiefly in the study of close double stars and of the spectra of the heavenly bodies. The late Professor Barnard discovered the fifth satellite of Jupiter by its visual aid.

Recently it has been pointed out that the less dense secondaries of the close eclipsing binaries mentioned above are generally relatively more tenuous than their primaries in the case of those pairs which have the less massive companions. This tends to support the idea of their origin as pairs by division of a single star, since the smaller bodies would probably expand relatively more after the fission owing to a slighter degree of cohesion under gravity.

CHAPTER XIV.

STAR CLUSTERS AND NEBULÆ.

By J. H. Reynolds, F.R.A.S.

INTRODUCTORY.

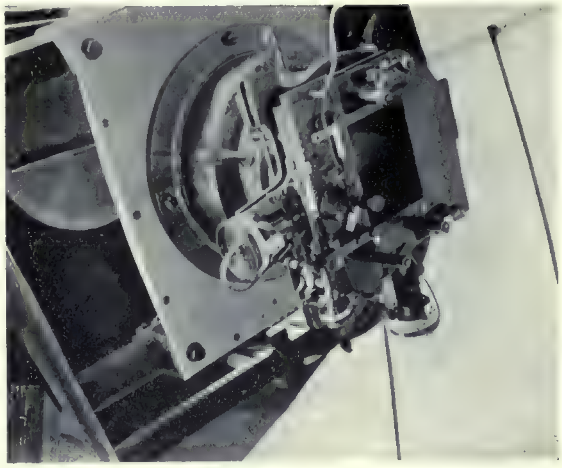
In no branch of Astronomy has the introduction of photography played such a decisive part as in the observation and classification of nebulæ and star clusters. Forty years ago, when Sir Robert Ball wrote "The Story of the Heavens," and Newcomb his "Popular Astronomy," very little more was known as to the constitution of these objects, and their place in the general structure of

the Universe, than was revealed by the Herschels fifty years before. The word "nebula" was at first indiscriminately applied to all objects of an ill-defined hazy character which could not be resolved into stars by the eye. Many of these, such as the coarse star cluster Praesepe in the constellation Cancer, the Andromeda Nebula, and the Magellanic Clouds were known in early times, but it was not until the introduction of the telescope that the stellar nature of the clusters was recognised. Even then the small aperture and imperfections of the primitive instruments led the early observers to describe many objects as nebulæ, which the more powerful and efficient reflectors of the Herschels showed to be clusters of stars. As the size and consequent light-grasp of telescopes was increased, so more and more of the so-called nebulæ were resolved into stars, and the idea naturally arose that it was only necessary to go on increasing the light-grasp of the telescope to find that all the nebulæ were stellar in their constitution. Thus arose the now abandoned distinction between resolvable and irresolvable nebulæ, which did not mean necessarily that the latter would always be irresolvable, but they were not resolved into stars by the instrument used at the time of observation. There is no record that the great nebula known as the Nebula in Orion was ever noticed until the introduction of the telescope. It was first described by Huyghens in 1659, in the following words: "There is one phenomenon

THE CROSSLEY REFLECTOR.

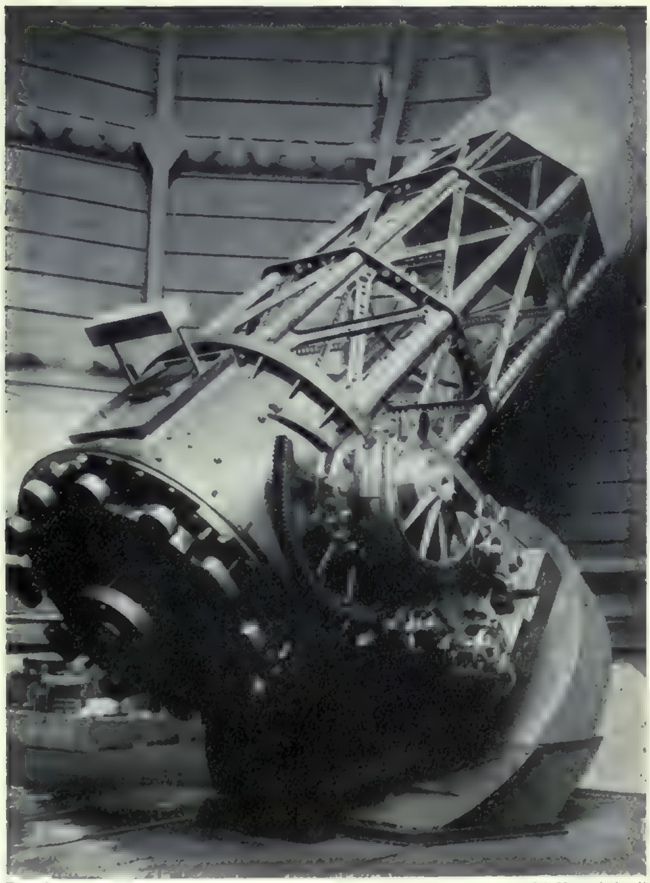
The Crossley Thirty-six-inch Reflector of the Lick Observatory in its original form, as mounted from Dr. A. A. Common's designs. It was with this instrument that many of the photographs reproduced here were obtained. This mounting has now been discarded in favour of a more rigid instrument, but the type was the basis of the large reflecting telescopes recently erected.

among the fixed stars worthy of mention, which as far as I know has hitherto been noticed by no one, and indeed cannot be well observed except with large telescopes. In the Sword of Orion are three stars quite close together. In 1656, as I chanced to be viewing the middle one of these with the telescope, instead of a single star, twelve showed themselves (a not uncommon circumstance). Three of these almost touched each other, and with four others, shone through a nebula so that the space around them seemed brighter than the rest of the heavens, which was entirely clear and appeared quite black, the effect being that of an opening in the sky through which a brighter region was visible." The old conception of the dark firmament which contained



THE FOCUSSING AND PHOTOGRAPHIC ATTACHMENT OF THE THIRTY-INCH REFLECTOR AT HELWAN, EGYPT.

The dark slide is carried in the rectangular space shown on the upper slide. The two slides can be moved at right angles to each other by means of micrometer screws.



From] [" *Knowledge*."

THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY, CALIFORNIA.

One of the three largest reflecting telescopes in the world, with which many of the photographs appearing here were obtained. In rigidity and general design it forms a great advance on previous instruments of this type.

the stars obscuring the glory of the empyrean may have been in Huyghens' mind when he thus described the impression the nebula produced on him. We shall see later that the Nebula in Orion is the great example of what are known as the irregular gaseous nebulæ. Another nebula of a totally different kind, also worthily designated "Great," is the Nebula in Andromeda. Easily visible to the unaided eye, it has frequently been mistaken for a comet, and lies a few degrees north-west of the bright star β Andromedae. It was first observed telescopically by Marius in 1614, who compared its light to that of a candle shining through horn.

To the naked-eye observer many of the star clusters appear as ill-defined circular patches of light, such as the two open clusters in Perseus, and the much condensed globular cluster ω Centauri, which was considered to be a hazy star when the Greek letters were assigned to the stars of the constellation in order of brightness. The first list of star clusters and nebulæ to be compiled and published was that of Messier, a French astronomer, in 1784. Messier came across a nebula

accidentally in searching for comets, and this list of 103 objects was issued so that they should not be mistaken for comets. Some of the nebulæ described by him as " Nebeleuse sans etoiles " are now well-known globular star clusters, a good example of the inefficiency of the eye in distinguishing

THE NEBULOUS BRIGHT CLUSTER IN SAGITTARIUS, M8, (N.G.C.6523). PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

A good example of the Galactic Diffuse Nebulæ, many bright stars being involved in the nebulosity, somewhat resembling the Pleiades. Specially noticeable are the dark patches, indicating absorbing matter between us and the Nebula. Owing to its southerly declination it is difficult to observe this object satisfactorily in England.

faint points of light with a small telescope. But it was not until Sir William Herschel early in the nineteenth century devoted himself to a thorough examination of the sky with the powerful instruments

THE OPEN STAR CLUSTER N.G.C.2437, IN ARGO NAVIS.
PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR, IN 1894.

One of the most impressive of the galactic clusters as seen in a large telescope. It is specially remarkable for the presence of a small annular nebula round one of the stars in the cluster, which can be seen in the northern portion. In astronomical photographs the south is usually at the top, and the north at the bottom.

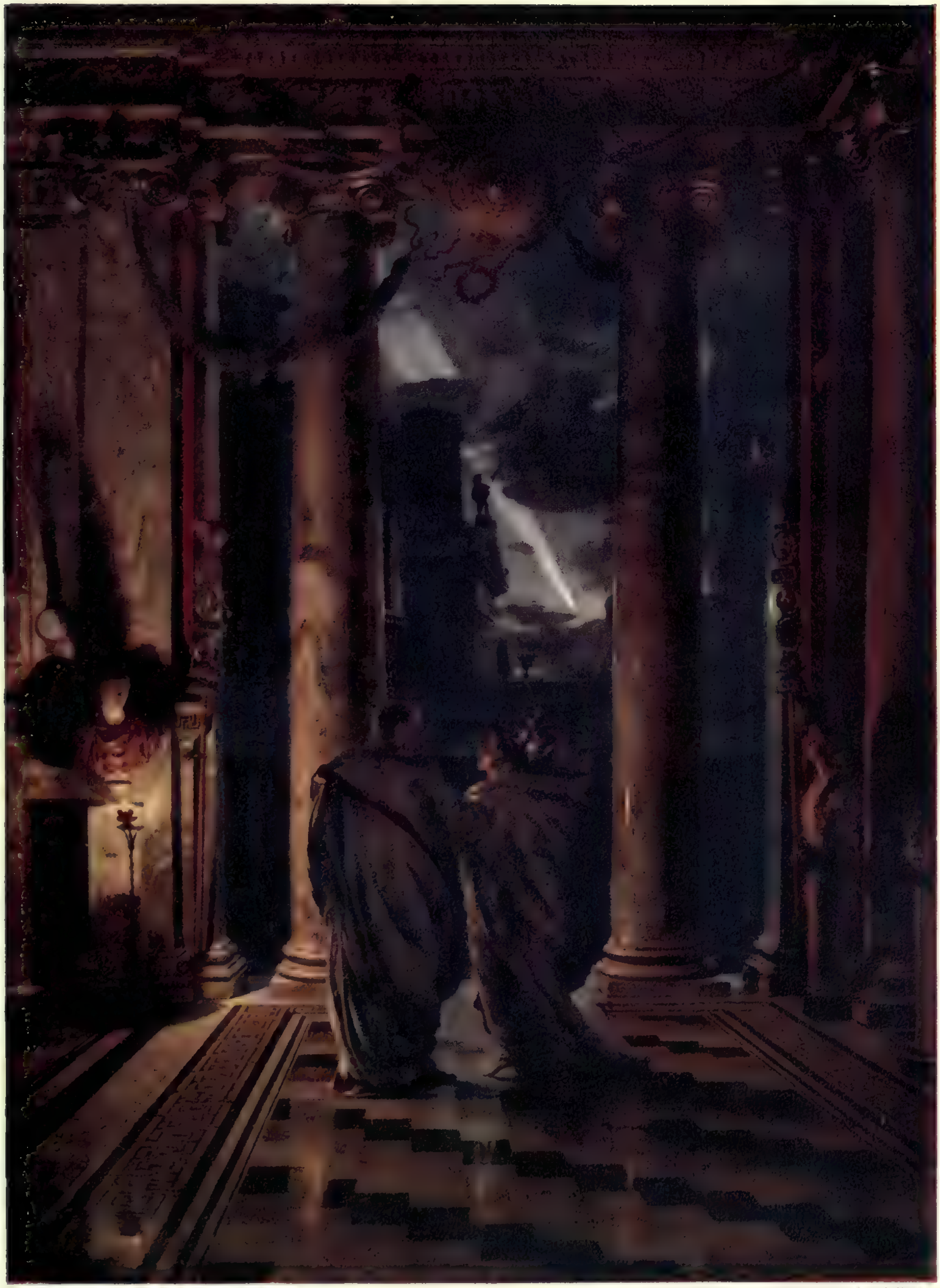
THE STAR CLUSTER M24 CLYPEI, N.G.C.6603.
PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR, IN 1895.

This is a local condensation in one of the two branches of the Milky Way, which is well shown in the photograph. The brightest stars are of about the seventh magnitude, and the faintest of about the seventeenth magnitude. The dark spaces of spiral form round the cluster are very remarkable.

he had constructed, that the importance of this branch of Astronomy became manifest. In this work he was helped by his sister Caroline, and was succeeded by his son Sir John Herschel, who completed in the Southern Hemisphere the work so ably accomplished in the Northern Hemisphere by his father. In 1864 the "General Catalogue of Nebulæ" appeared in the Philosophical Transactions of the Royal Society, containing 5,079 objects, of which only 450 were due to other observers than the Herschels. This has necessarily formed the basis of the New General Catalogue of Dr. J. L. E. Dreyer, issued by the Royal Astronomical Society in 1888. Dr. Dreyer (now President of the Royal Astronomical Society) included in his catalogue all other known observations of nebulæ, and the total number of objects was thus increased, with the two additional Index Catalogues, to well over 10,000 objects. This catalogue has been regarded ever since its publication as the standard work for observers of nebulæ and star clusters all over the world, and it is by the numbers therein affixed that the objects are generally known. Visual observation at the telescope was continued until the early 'eighties of the last century, notably by Lord Rosse with his gigantic, but roughly mounted reflector of six-foot aperture at Parsonstown. Meanwhile another line of attack had been devised by Sir William Huggins with the spectroscope. Most of his early work was devoted to the spectra of the stars, but in 1864 he thought of applying the new method to the nebulæ, and he chose a small bright nebula with an elliptical disc in Draco, of the class termed "Planetary Nebulæ" by the Herschels. He found to his surprise, on looking through the eyepiece of the spectroscope, that the light of the nebula, instead of being spread out along the spectrum as in the Sun and stars, was concentrated in a single line in the green. He thought at first there was some lack of adjustment in the instrument, but soon convinced himself that the appearance was real

THE CLUSTER HERSCHEL VI, 37 IN ARGO NAVIS, N.G.C.2506. PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR, IN 1894.

Lord Rosse, who records nine observations of this cluster between the years 1849 and 1856, thought he saw a spiral appearance about the brightest star and a general nebulous character in the cluster. This is not borne out by the photograph, which shows no trace of nebulosity.



From the painting by Sir E. J. Poynter, P.R.A *by permission of the Manchester Art Gallery*

"THE IDES OF MARCH."

The artist appears to have antedated the appearance of this Comet. He represents Calpurnia, the wife of Julius Cæsar, as pointing out to her husband the alarming apparition. Actually Julius died on 15th March, 44 B.C., while the Comet was not seen before June, the month given by the Chinese. The Latin authors describe its brightness during the games instituted by Augustus in September of the same year. Augustus put a star (suggested by the Comet) over the head of his statue of Julius: his idea was that the Comet was the soul of Julius ascending to heaven. (See Chapter X.)

THE STAR CLUSTER HERSCHEL VI, 30, IN CASSIOPEIA, N.G.C.7789. PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR, IN 1898.

A good example of the open clusters in the Milky Way. These are much more numerous than the isolated groups of bright stars or the globular clusters. It has been suggested by Dr. Shapley that these were originally globular clusters which have entered the galactic regions and become to some extent dispersed. This is not improbable, as the globular clusters in general have a motion of approach to the Galaxy.

and not illusory, and the only possible interpretation was that the nebula consisted of radiating gas. On the other hand, he found that not all nebulæ showed emission gaseous spectra, but some, such as the Nebula in Andromeda, gave a continuous spectrum like the stars. Huggins therefore definitely established the existence of two classes of nebulæ: those which were gaseous and those with a spectrum resembling the stars. It was at this juncture, when any great advance by visual telescopic observation seemed improbable, that photography was called in to assist the eye. By placing a photographic plate in the focus of the telescope in place of the eyepiece, it was found that an impression was made of faint stars which were beyond the limit of visual observation with the same telescope, and it occurred to Dr. A. A. Common, of Ealing, in 1881, to apply this new method to the photography of nebulæ. He was soon rewarded by magnificent photographs of the Orion

THE DOUBLE CLUSTER N.G.C.869,884 IN PERSEUS. PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR, IN 1895.

These well-known clusters, visible as a nebulous patch to the unaided eye, are striking objects even in a small telescope. They are more condensed than these galactic clusters usually are.

THE GLOBULAR CLUSTER HERSCHEL 52, IN TOUCAN, -N.G.C.104. PHOTOGRAPHED WITH THE VICTORIA PHOTOGRAPHIC REFRACTOR OF THE CAPE OBSERVATORY.

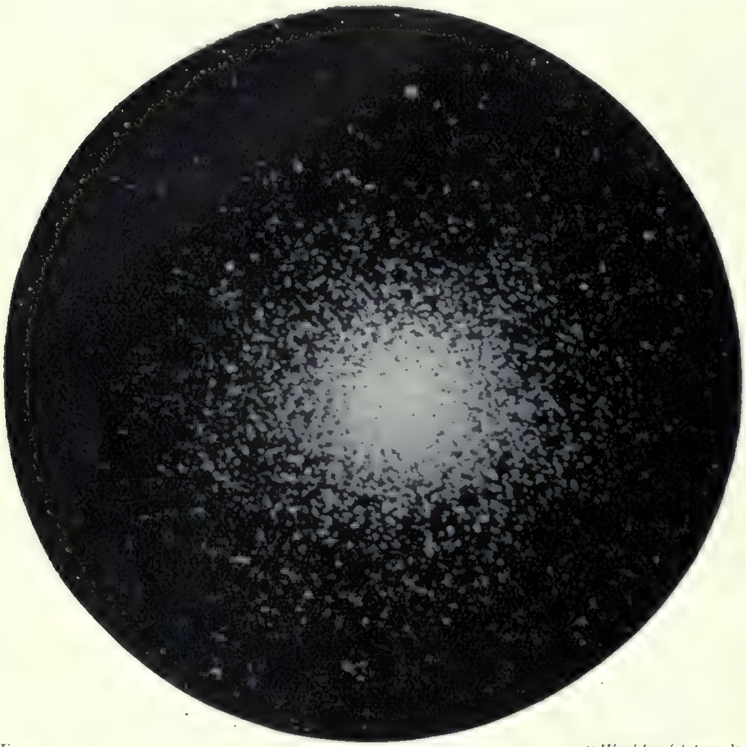
The second in order of size and magnitude in the Southern Hemisphere of the sky. It was described by Sir John Herschel as having a central mass of white stars with a fringe of red ones. Later observations do not bear this out.

Nebula, which revealed in a few minutes' exposure with his large reflector details not recorded at all in the laborious and painstaking drawings of this object by G. P. Bond at Washington twenty years before. This success was quickly followed up, first by Dr. Isaac Roberts with his twenty-inch reflector at Crowborough, and in America at the Lick Observatory by Keeler with a thirty-six-inch reflector constructed by Dr. Common and Mr. Calver for Mr. Crossley, of Halifax, and presented by that gentleman to the Lick Observatory. By 1900, many hundreds of photographs of nebulæ and star clusters had become available for scrutiny and measurement, and the application of photography to the spectroscope assisted in the determination of the type to which the objects should be assigned. In 1908 a thirty-inch reflector was installed at the Helwân Observatory in Egypt to deal with the Southern Nebulæ, and the sixty-inch and now the hundred-inch reflectors at Mount Wilson, mounted with all the precision modern engineering is capable of giving, are engaged on the photography of nebulæ and star clusters according to a definite programme of work, which maps out the whole of the available time during which these great instruments can be employed.

THE PHOTOGRAPHY OF NEBULÆ AND STAR CLUSTERS.

Dr. Steavenson, in the first chapter of this work, has dealt with photography as applied to astronomical research generally, and has mentioned the preference given to reflectors in recent years. The principal reason of this preference is the great light grasp which can be attained by this type of instrument. As in a camera the brightness of the image of an extended object (and consequent duration of exposure) depends on the focal ratio, so in a reflecting telescope, the mirror ground and polished to a curve giving a focal ratio of F.5 produces a much brighter image than a refractor of a focal ratio of F.15. In dealing with excessively faint objects such as nebulæ this is a tremendous advantage, and all the recent work on nebulæ which has led to such important results has been achieved by reflectors of twenty-inch aperture and upwards. Another reason why reflectors are so efficient for photography is the fact that not only the visual part of the spectrum but also the portion lying in the ultra violet is represented in the focal image without much loss, and the gaseous nebulæ are usually very rich in this invisible light. Again, the production of a large mirror having only one surface to be polished and figured is an easy matter compared with the four and sometimes six surfaces of a large lens, the thickness of which is in itself an impediment to light, and especially to ultra violet rays. The production of the perfectly figured parabolic mirror, although important, is, however, only a part of the work to be done, and all the refinements of modern engineering have

to be employed in its mounting, so that the focal image can be impressed on the photographic plate accurately during a long exposure. The reflecting telescope is, in fact, a huge camera with a parabolic mirror instead of a lens, mounted on an axis parallel to that of the Earth, and provided with a mechanism driving it from east to west, so that the diurnal rotation of the earth from west to east is precisely counteracted. If a star which is imprinting its light on the photographic plate is allowed to deviate from its true position by one-hundredth of a millimetre the effect will be not a circular dot, but an ellipse, and every other point on the photographic plate will be displaced to the same extent, with the result that the photograph will not be capable of accurate measurement. Some large reflectors are provided with electric control, an arrangement originally devised by Sir Howard Grubb, in which an independent seconds pendulum either accelerates or retards the driving of the telescope by means of relays and differential gears. The thirty-inch reflector at Greenwich has such an arrangement. In America the same result has been attained, not by electric means, but by great mechanical refinements in the rotating frictional governors, the balls or discs not moving up and down in a circular but in a parabolic curve, so adjusted that there is a very small difference in rate between the highest position and the lowest. This has been found to act very well as applied to the gigantic sixty-inch and hundred-inch reflectors at the Mount Wilson Observatory. But neither the electric or mechanical control is sufficient to ensure the accuracy essential for the long exposures necessary for the faint nebulæ. The ingenuity of Dr. A. A. Common, of Ealing, gave us the piece of apparatus which has now been almost universally adopted for this kind of work. Instead of the plateholder being mounted immovably at the focus of the reflector, it is carried on a double slide which is capable of movement in two directions at right angles to each other, corresponding to the motion in right ascension and declination of the telescope itself. It is obvious that if a star just off the edge of a plate is observed through a highly magnifying eyepiece containing illuminated cross-wires, any motion of the star away from its proper position will be reproduced all over the plate. Each of the slides carrying the plateholder can be moved by fine screws with large divided milled heads, so that by turning these, the star can again be brought on to the cross-wires and the whole field of the photograph corrected by an equal amount. The writer has found it best to have a double set of cross-wires forming a minute square in the centre of the eyepiece field, as it is easier to centre the brightest point of the star image, distorted by its distance from the optical axis, in this square than to keep it on the intersection of two illuminated wires. Another matter of great importance is the position of the focal plane. Unless this is accurately



From, *"Worlds of Space."*

THE GLOBULAR CLUSTER, ω CENTAURI.

Although this cluster, both from its dimensions and the magnitudes of its component stars, is undoubtedly the finest object of this class in the whole sky, it has not yet been photographed with a large reflector owing to its considerable southern declination. One of the best photographs so far obtained is that of the Franklin Adams Charts.

THE GLOBULAR CLUSTER IN HERCULES, M.13, N.G.C.6205. PHOTOGRAPHED WITH THE SIX-FOOT REFLECTOR OF THE DOMINION OBSERVATORY, OTTAWA, BY J. S. PLASKETT.

This photograph of the best known globular cluster in the Northern Hemisphere shows very well the difference in magnitude between the stars forming the cluster. Probably the brighter ones are "giants" and the fainter ones "dwarfs." The exposure has not been so prolonged as to merge the central portion into a bright mass in which the individual stars are indistinguishable, as in most photographs of this object.

From "Knowledge."] [Photo by Prof. Keeler.

THE GLOBULAR CLUSTER M.12 IN OPHIUCHUS, N.G.C.6218. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

This cluster is neither so rich nor so condensed as the majority of globular clusters, and is intermediate between these and the galactic type of open clusters.

attained to a hundredth of a millimetre, the full light value of the mirror is lost on star images owing to the wide angle of the cone, and those of fainter magnitudes do not register themselves on the plate. A question of considerable interest is the degree of faintness of a star which can be photographed. It is known that the seventeenth magnitude is about the limit of visibility even in large instruments; by photography under the best conditions the twenty-first magnitude has been reached with the large reflectors in America, and with a very perfect fifteen-inch mirror by Mr. C. R. d'Esterre in this country. It is doubtful whether this will be greatly extended in the future.

When a comparatively slow plate is used to get rid of the effect of grain, very prolonged exposures are necessary, and sometimes are made on consecutive nights. This entails a most accurate registration of the position of the plate, so the plateholder is furnished with three conical pointed screws which fit into similarly shaped recesses on the first moveable slide. The guiding eyepiece is also mounted on a slide capable of motion in the two directions by screws. An illustration of the photographic and focussing attachment of the Helwân reflector is given on page 525.

Some details as to the construction and working of the two great reflectors at Mount Wilson Observatory may be of interest. The sixty-inch was completed in 1910 from designs by Professor Ritchey, who also directed the grinding and polishing of the large mirror. Its mounting is of the "open fork" type. The telescope, supported on trunnions bolted to a heavy cast-iron base, carries the mirror at its lower end and consists of an open tubular framework above. The fork formed by the trunnions and base, is attached to the top of the polar axis, a massive steel forging revolving in bearings at the requisite angle (thirty-five degrees, the same as the latitude) and placed accurately north and south. A good proportion of the weight of the moving parts is taken by a steel drum at the upper end of the axis below the fork, floating in a mercury trough. The quick and slow motions are manipulated by electric motors, the controlling wires being taken up to the eye end of the telescope. The Newtonian attachment with its forty-five degree plane mirror is in a separate cage bolted to the end of the framework tube, the parabolic mirror coming to its principal focus at

twenty-five feet. Two other cages carry convex mirrors which flatten out the focal cone of the great mirror to equivalent focal lengths of eighty and one hundred and twenty feet respectively. In each of these the focal image can either be reflected by a small plane mirror on to the upper side of the cast-iron body of the telescope or down the centre of the polar axis to an equal-temperature chamber below for spectrographic work. The nebular photographs obtained with this instrument are by far the finest yet produced, and many of them are reproduced in this work. The other great instrument, the one-hundred-inch reflector, is of much more recent construction, as it has only been completed since 1918. An illustration of it appears on page 39. In this case it was decided to mount the telescope in a closed fork supported above as well as below, as in consequence of the great weight, it was not considered safe to rely on the open fork type. The great disadvantage of this closed fork is that it is impossible for the telescope to be brought to bear on objects near the North Pole of the sky. When the great disc of glass, one hundred inches in diameter and thirteen inches thick was first tested, Professor Ritchey reported a permanent set of the glass along one diameter which prevented a perfect focal image from being obtained, and it was only after considerable hesitation that the work of grinding, polishing and figuring was prosecuted to a conclusion. The result, however, has fully justified the risk taken, as the beautiful photographs of the Moon and Nebulæ which it has already produced sufficiently prove. The enormous revolving dome of 120 feet diameter is, from the engineering point of view, undoubtedly the most wonderful piece of work yet produced in this direction, especially considering its altitude at 6,000 feet above sea-level.

THE GLOBULAR CLUSTER M.5 IN LIBRA, N.G.C.5904. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

A much-condensed cluster of twelfth to seventeenth magnitude stars. Most of the globular clusters are near the Milky Way, but this is in a barren region of the sky, containing no nebulæ and only a few faint stars.

[G. W. Ritchey.

THE GLOBULAR CLUSTER M.3 IN CANES VENATICI, N.G.C.5272.

PHOTOGRAPHED WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

This cluster lies near the North Galactic Pole and is one of the finest visible in northern latitudes. The amazing degree of condensation in the centre can readily be seen, as the separate star discs cannot be distinguished owing to their number. Many thousands of stars from the twelfth to the seventeenth magnitude are included in this small area of sky. Some of the stars are short-period variables of the type known as Cepheids.

THE DISTRIBUTION OF THE STAR CLUSTERS AND NEBULÆ IN THE SKY.

We now come to an important question which has a great bearing on the whole structure of the Universe, as far as we can ascertain its limits. No description of the star clusters and nebulæ would be complete, or even intelligible, without giving the results of recent research on the grouping of these objects in certain regions of the sky. Astronomers recognised in very ancient times that the celestial sphere apparently revolved on an axis once a day, and the North Pole of this axis now lies near the North Star in Ursa Minor. The equator of the sphere naturally was the great circle the position of whose poles was determined by the direction of the Earth's axis, and the positions of all objects in the sky are referred to this great circle and the poles in what are known as Right Ascension and Declination, corresponding to terrestrial Longitude and Latitude. Another division of the sphere is made by the great circle known as the Ecliptic, which is the apparent path of the Sun in the sky during the year. The position of the planets and comets are referred to this circle and to its poles in celestial Longitude and Latitude. It is evident that the first is purely terrestrial, while the second applies to the Solar System as a whole. But there is another division of the celestial sphere which is of much greater importance than either of these, for the Milky Way approximately forms a great circle of the sky, and although it varies in width, sometimes with considerable irregularities, a line can be traced along its entire course dividing the sphere into hemispheres. This is called the Galactic Equator, its poles lying in the northern constellation of Coma Berenices, and in the southern constellation Cetus. It has in recent years become usual to refer the positions of stars and nebulæ to this division of the sphere, as it is evidently of fundamental importance, and not merely local as the other two divisions must be. Sir William Herschel

THE GLOBULAR CLUSTER M.15 IN PEGASUS, N.G.C.7078. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.
Like the cluster in Libra, this lies in a barren region of the sky.

was the first in the field in this, as in many other questions connected with stars and nebulæ. He came to the conclusion that there was a concentration of nebulæ towards the North Pole of the galactic sphere, and Sir John Herschel, after his work at the Cape, came to a similar conclusion as to the South Pole. Neither of them was entirely correct in this, although the evidence they got certainly made it seem reasonable, and it was left for the photographic survey of the sky during the last thirty years to reveal to us what the distribution of these objects really is. Broadly speaking, the globular star clusters are congregated in one hemisphere of the sky, its pole being in the Milky Way in Sagittarius, while the large spiral nebulæ predominate in the other hemisphere. The probable meaning of the distribution will be discussed when we come to deal with the spiral nebulæ. On the other hand, the diffuse, irregular and dark nebulæ are all galactic objects, most of them within ten degrees of the galactic equator. The planetary nebulæ, which without exception give a gaseous emission spectrum, have the same general distribution as Wolf-Rayet stars, and can safely be considered also as forming part of the galactic system. The classification of star clusters, apart from nebulæ, is an easy matter compared with what it was in the days of visual observation only, and we can proceed at once to deal with this class of objects, leaving the nebulæ to be discussed in a later section.

THE DIFFUSE NEBULA H. V 30 IN ORION, N.G.C.1977. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

This gaseous nebula is just to the north of the Great Nebula in Orion, and evidently forms part of it, from which it is separated by a wide band of absorbing matter. Its spectrum is similar and it includes some bright stars involved in the nebulosity.

STAR CLUSTERS.

These are found in various regions of the sky in all degrees of compression, from the loose aggregations of bright stars such as the Pleiades, the Hyades in Taurus, and Praesepe in Cancer,

DIFFUSE NEBULA AND BRIGHT STAR GROUP IN MONOCEROS, N.G.C.2237/9. PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR, IN 1899.

This nebula lies in the Milky Way not far from Orion and is similar in type to the nebula M.8 in Sagittarius, also connected with bright stars. Such nebulæ do not always give a gaseous emission type of spectrum, but sometimes a continuous type is produced, indicating that the nebula is made visible by reflected light from the stars.

From] ["Knowledge."

NEBULOUS REGION NEAR RHO OPHIUCHI. PHOTOGRAPHED BY PROFESSOR E. E. BARNARD WITH A SIX-INCH PORTRAIT LENS.

The area represented in this photograph is much greater than in the previous illustrations, and covers a large field of the Milky Way. The dark spaces which are so conspicuous are probably absorbing matter, which is lit up by bright stars and appears around them as luminous nebulosity.

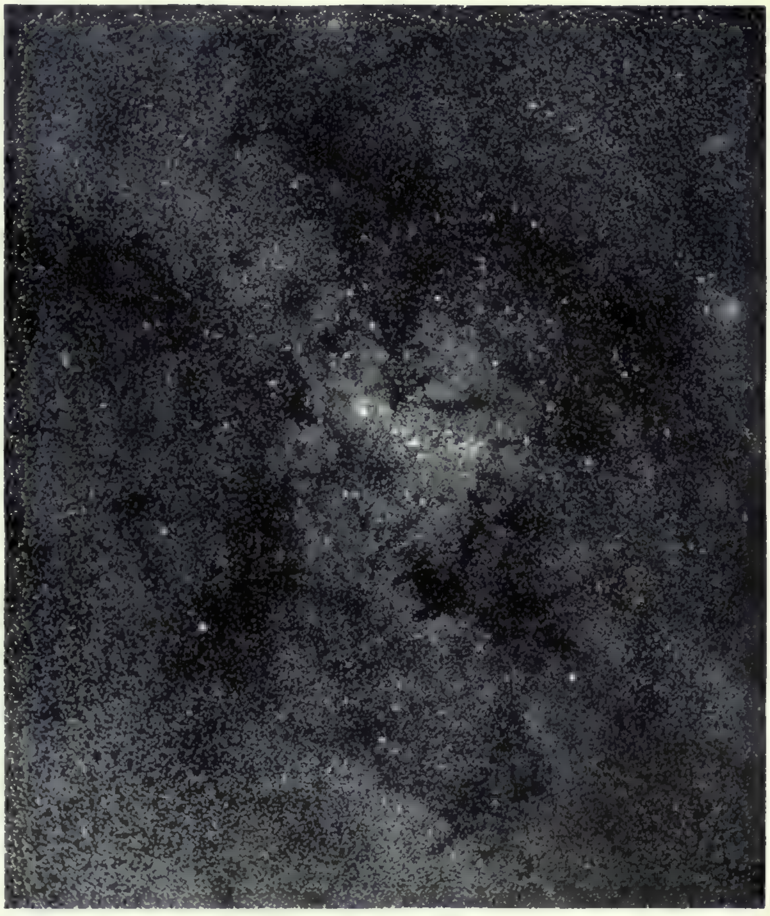
which are comparatively close to us, to the small densely packed and centrally condensed clusters of faint stars which are known as "globular." It will be best to divide these objects into three classes, although there are no well-defined limits between them.

(1) The large groups of comparatively few bright stars.

(2) Open clusters, by which is meant clusters of some hundreds of ninth to fourteenth magnitude stars with little central condensation.

(3) The globular clusters containing many thousands of faint stars of twelfth magnitude and fainter, condensed in the centre to such an extent that individual stars cannot be distinguished.

There are only a few examples of the first class in addition to the Pleiades, the Hyades, and Praesepe already mentioned, and the majority of the others appear in the neighbourhood of the Milky Way in the Southern Hemisphere of the sky. The brightness of the stars is an indication that they are comparatively close to the Solar System compared with the globular clusters. We will take the Pleiades as a type of this class; first of all because it is the best known, and secondly because it has been studied and measured more than any other group of stars. It was well known in ancient times, and is often mentioned in Eastern and classical literature. Whether this group was actually intended by the writer of the Book of Job is doubtful, as the identification of the seven stars with the Pleiades by the translators was only a more or less probable surmise. It is, however, mentioned by Homer in the Odyssey, and by Virgil in that early astronomical treatise on the seasons and their influence on agriculture, the "Georgics." Six or more fairly bright stars can readily be seen at a glance on a fine night; the telescope shows well over a hundred. In photographs there are many more faint stars, but it is probable that only the brighter stars actually belong to the group, the remainder forming a distant background. From the ancient records there is reason to think that the principal stars forming the group have varied in relative brightness. Thus Alcyone, the "lucida," or brightest star, now of the third magnitude, was either not one of the four Pleiades observed by Ptolemy, or else was much fainter than it later became. Next in brightness come Electra and Atlas, each of 3·6 magnitude; Maia of the fourth magnitude; Merope and Taygeta, both between the fourth and fifth magnitude;



NEBULOUS REGION IN CEPHEUS. PHOTOGRAPHED WITH A CAMERA LENS OF THE PORTRAIT TYPE AT THE YERKES OBSERVATORY.
This photograph is on a considerably smaller scale than others appearing in this chapter, and covers about four times the area of Dr. Roberts' photographs. The irregular dark areas probably consist of absorbing matter between us and the Galaxy.

and Pleione of 5·4 magnitude, with a gaseous spectrum like some variable stars. The interdependence of the brighter stars of the Pleiades is undoubted; they all have the same proper motion (according to Newcomb) of six seconds a century, and the discovery in 1886 by photography, that the whole group is enveloped in nebulosity, made this interdependence doubly certain. The character of this nebulosity may be seen from an examination of the plate on page 56, an extraordinary characteristic very seldom encountered being the stringing together of several stars by a long wisp of nebulosity. In recent years the additional discovery has been made by Slipher at the Lowell Observatory, in Arizona, that the spectrum of the nebulosity is identical with that of the involved stars, and we are justified in concluding that the nebulosity is made visible to us by reflected light, in much the same way as the Zodiacal Light is made visible by the reflected light of the Sun. The spectrum of the brighter stars is that known as the B type of the Harvard scale, in which hydrogen and helium absorption lines are the principal characteristics. It may be asked whether it is possible to estimate the distance of this wonderful collection of bright stars. There can be no doubt that they lie at a great distance from the Solar System, so that it would take something like 200 years for their light to reach us. At such a distance our Sun would not be visible to the unaided eye at all, appearing as a telescopic star of 8·6 magnitude. Even Sirius, the brightest star in the sky, would occupy a subordinate position in this assemblage if removed to an equal distance. If we take the whole group as being roughly globular, the light would take six years to pass through it, and its diameter would be half as great again as the distance between us and the nearest bright fixed star (α Centauri). The great intrinsic brilliance of its individual stars can be gathered from their spectra, which are higher in the scale of temperature than stars such as Sirius, where broad bands of hydrogen are the marked feature

THE DIFFUSE NEBULA N.G.C.281 IN CASSIOPEIA. PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH, WITH THE TWENTY-INCH REFLECTOR.

A galactic nebula associated with stars and dark spaces. The region of the Milky Way in Cygnus and Cassiopeia is the brightest in the northern sky, and contains many examples of nebulæ of this type.

From] [" *Knowledge.*"

THE TRIFID NEBULA IN SAGITTARIUS M.20, N.G.C.6514. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

One of the three great diffuse nebulæ in the star clouds of Sagittarius, where the Milky Way is densest. This nebula is probably a portion of a dark cloud of matter lying across the nebulous region. The dark spaces and lanes are apparently between us and the nebula.

From] [" Knowledge."

THE "AMERICA" NEBULA IN CYGNUS, H. V 37. PHOTOGRAPHED BY E. E. BARNARD WITH A SIX-INCH PORTRAIT LENS.
One of the great diffuse galactic nebulæ apparently connected with a dark cloud of absorbing matter. The difference in the number of the stars in the upper and lower halves of the plate is quite striking, only a few of the brighter stars appearing in front of the "cloud." A dark patch of absorption near the edge of the cloud is also remarkable for its clearly defined outline. The bright patches are stars involved in nebulosity.

of the spectrum. A similar group of stars in all probability much more remote than the Pleiades, and involved like them in nebulosity, is to be found in the constellation Sagittarius, near the richest parts of the Galaxy. This is the eighth in the list formed by Messier, but it is difficult to observe or to photograph it in this country owing to its southerly position in the sky, and the shortness of the summer nights when it passes the meridian at midnight. It has, however, been photographed successfully in more southerly latitudes, in Egypt and in California. Sir John Herschel says in his "Outlines of Astronomy," "It is a collection of nebulous folds and matter, surrounding and including a number of oval dark vacancies, and in one place coming up to so great a degree of brightness as to offer the appearance of an elongated nucleus. Superimposed upon this nebula, and extending in one direction beyond its area, is a fine and rich cluster of scattered stars, which seem to have no connection with it, as the nebula does not, as in the region of Orion, show any tendency to congregate about the stars." And yet photography has conclusively proved that there is a very definite connection between the stars and the nebulosity in which they are involved, as stars arranged in curves are connected by wisps of nebulosity similar to those in the Pleiades. Another group well known in ancient times is Praesepe, in the constellation Cancer. In this case there is no involving nebulosity, and the type of predominant spectrum is similar to that of the Sun, indicating a much lower temperature than the stars forming the Pleiades. Much attention was paid to this congregation of stars in the latter half of the last century, and their positions accurately determined by visual observation at the telescope. There can be no doubt as to their mutual interdependence and in a small telescope they form a striking collection of bright stars, most of them just beyond the limit of naked eye visibility. Amongst the groups of comparatively bright stars may be mentioned the

IRREGULAR NEBULA N.G.C.1499 IN PERSEUS. PHOTOGRAPHED AT DR. ISAAC ROBERTS' OBSERVATORY AT CROWBOROUGH WITH THE TWENTY-INCH REFLECTOR.

One of the filamentous nebulæ which are usually found in connection with dark clouds of absorbing matter in the Milky Way. There is evidence of such a dark cloud on the left-hand side of the photograph where stars are comparatively few.

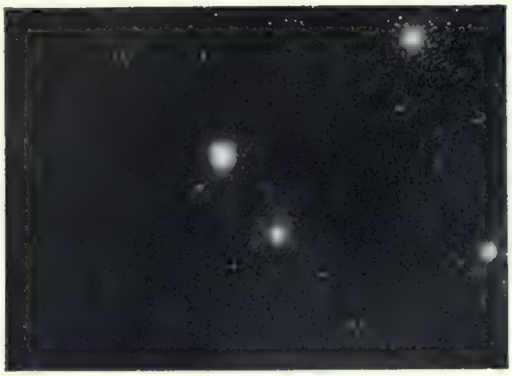
Hyades, near Aldebaran in Taurus, and Coma Berenices—an extended mass of stars near the north galactic pole. The position of many of these groups in the sky is right away from the Galaxy; this fact, coupled with their comparative brightness, is in itself evidence that they lie closer to us than the next class of star clusters, which are known as "open" clusters. Broadly speaking, the open clusters are galactic objects; that is to say, they appear usually in or near the Milky Way itself. They are much more numerous than the coarse groups we have already considered. Melotte, from an examination of the Franklin Adams plates of the whole sky, includes 147 objects under this head. Perhaps the most conspicuous examples in the northern sky are the two beautiful clusters in the sword handle of Perseus. Another, in Gemini (N.G.C.2168), is a fine object in a large telescope. Others in Cassiopeia are well worth examination, and photographs show strongly how some of the clusters concentrate towards the centre. But in the writer's estimate, the finest of all is the cluster N.G.C. 2437 Argûs, in the southern sky, below Sirius in the Milky Way. Viewed with the thirty-inch reflector of the Helwân Observatory in Egypt, it is a brilliant object, and an extraordinary feature not found elsewhere is that one of the cluster stars, not differing from the others in apparent magnitude, is surrounded by a ring of nebulosity. A remarkably good photograph of this cluster and the ring nebula appears in Dr. Isaac Roberts' second volume of photographs, and is reproduced on page 527. As at its highest culmination at Dr. Roberts' Observatory at Crowborough it was not more than 25° above the horizon, it says much for the skill and determination of the observer that an exposure of twenty minutes was given with such excellent results. Sir John Herschel observed it at the Cape, and first drew attention to the small ring nebula round one of the stars. There is not so much concentration towards the centre of this cluster as in others of this class, and it may be regarded rather as a local concentration of the Milky Way. If we were to imagine a sphere

NEBULA ROUND THE STAR ν SCORPII. PHOTOGRAPHED BY PROFESSOR E. E. BARNARD IN 1895 WITH A SIX-INCH PORTRAIT LENS.

The nebulosity surrounding the star stretches for some distance, but its illumination is probably due to the star itself and possibly one or two other bright ones in the vicinity. The dark halo round the star is a photographic effect, owing to the plate used being unbacked.

FILAMENTOUS NEBULA IN CYGNUS, N.G.C.6960. PHOTOGRAPHED BY MR. G. W. RITCHEY WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

The bright round patch at the top of the photograph with four diffraction rays is the star κ Cygni. It will be noticed that the stars on one side of the nebula are much more numerous than on the other; it is probable, therefore, that the nebula forms the bright illuminated edge of a dark cloud of absorbing matter similar to that in the illustration of the dark nebula near ζ Orionis. (See page 47.) The nebula is in reality a very faint object, but a prolonged exposure and photographic manipulation have made its faintest details very apparent.



THE NEBULOUS REGION CONTAINING THE VARIABLE NEBULA ATTACHED TO THE VARIABLE STAR R CORONAE AUSTRALIS. PHOTOGRAPHED WITH THE THIRTY-INCH REFLECTOR OF THE HELWAN OBSERVATORY.

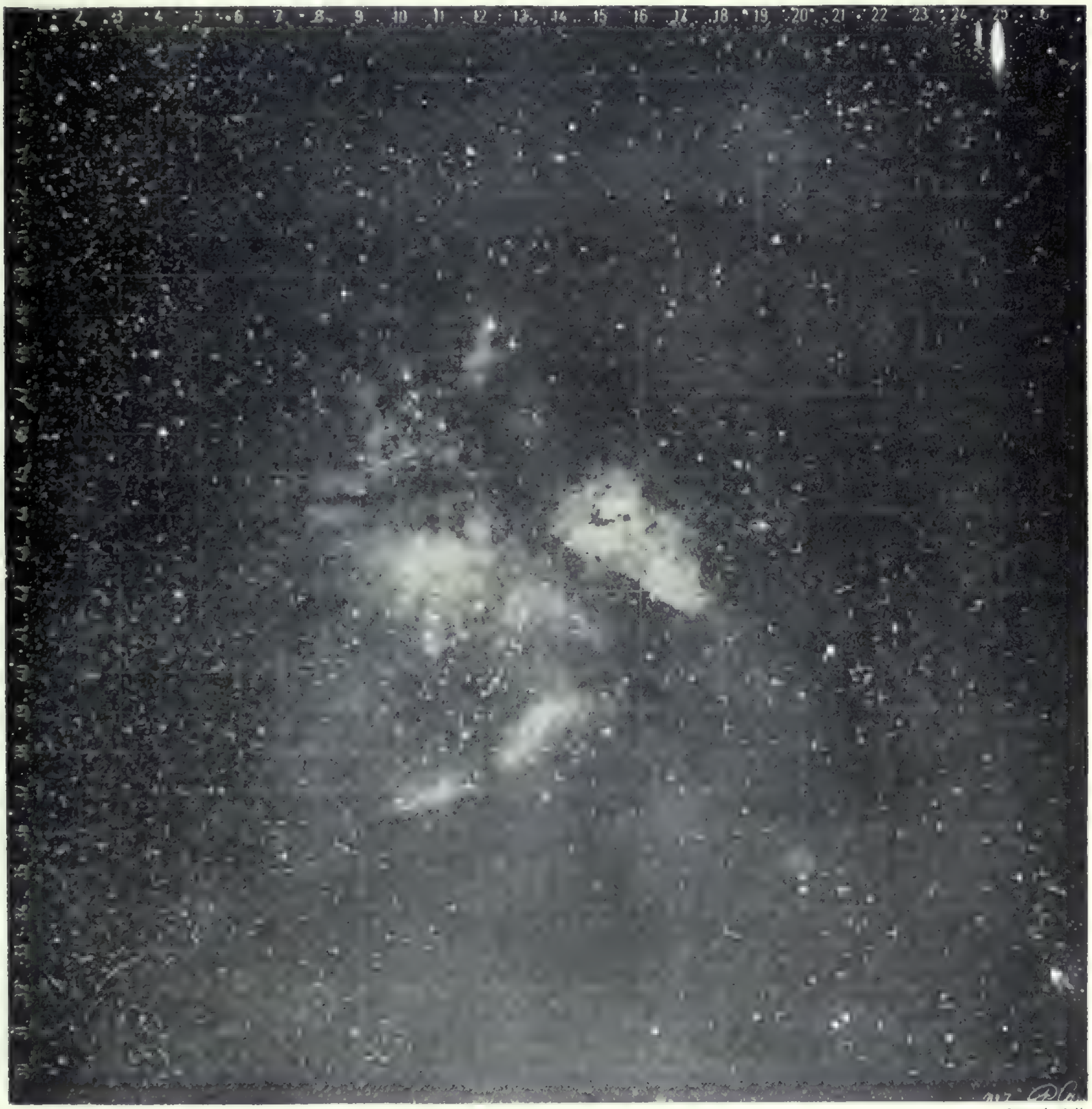
This is a reproduction without enlargement of an interesting region in the southern sky, which lies about 20 degrees from the plane of the Galaxy. A dark area with a few bright stars surrounded by nebulosity includes the variable nebula, in appearance rather like a comet, which lies below and a little to the left of the bright nebulous patch. A globular star cluster appears in the corner of the plate.

containing stars equally interspaced, we should get, by the effect of perspective alone, a great concentration towards the centre. This question has been made the subject of special study by Professor Plummer and others, and has an important bearing on investigations of the third class—the globular clusters.

THE GLOBULAR CLUSTERS.

These are without doubt the most important as well as the most beautiful of the clusters. Although the apparently smaller and fainter objects are found in and near the Milky Way, there are remarkably fine examples in regions far removed, some even near the galactic poles. The cluster known as ω Centauri, in the southern sky, the two clusters in Hercules, the clusters in Canes Venatici and in Pegasus, are all well-known telescopic objects, and as seen with large reflectors are truly magnificent. But it is only by means of photographs that we can adequately study and appreciate their dimensions and the enormous concentration of faint stars, so massed together in the central regions that the individual star discs cannot be separated. In the northern sky, the cluster in Hercules, Messier 13, mentioned by Halley in 1710, is the finest and best known. It lies in a comparatively barren region of the sky, so that its entrance into the field of view of a large telescope is surprisingly impressive. The brightest stars are of about the twelfth magnitude, but others are of the fourteenth and fifteenth magnitudes, and there seems to be a well-marked division between the magnitudes, the brighter ones being probably giants and the fainter ones dwarfs. A study of the spectra of these stars confirms this conclusion, as the brighter ones are of the solar type, probably on the upgrade of temperature, while the fainter ones are of the hydrogen type. A well-marked tendency for the stars to be arranged in curves has suggested that the globular clusters had their origin in spiral nebulæ, but until we can find some connecting link between these globular star formations and the thin spread-out planes of the spirals, we are on rather unsafe ground in drawing such a conclusion. The largest and brightest Globular Cluster in the whole sky is undoubtedly ω Centauri. This brilliant object has been photographed at the Cape by Sir David Gill and by Mr. Franklin Adams, and a photograph of it is reproduced on page 532. We cannot be wrong in assigning to this cluster the position of greatest proximity to the Solar System. Shapley in America has shown that there is a definite relation between the angular diameters and the magnitude of the stars in the globular clusters, and he therefore groups the clusters according to these characteristics. Another fine globular cluster, second only to ω Centauri in the southern sky, is that in Toucan, near the lesser Magellanic Cloud, described by Sir John Herschel as a mass of white central stars with an outer fringe of red ones. This has not been borne out by later observation, and Miss Agnes Clerke says that in 1888, when she saw the cluster with the large refractor at the Cape, "The sheeny radiance of this exquisite object appeared of uniform quality from centre to circumference." A very extraordinary characteristic of some of the globular clusters is the number of short period variable stars found therein. These stars are of the class known as the "Cepheids," and their variation between maximum and minimum takes place in a few hours, seldom as long as a day. They will be dealt with in their place in the chapter on "Variable Stars," but as they have been taken as a criterion for judging distances and the scale of the globular clusters, a few words of explanation here will not be out of place. The variability does not lie only in brightness, but also in the intensity and

displacement of lines in the spectrum, so that it is very unlikely that the change in brightness is due to an occulting star, as in the case of Algol, and a much more probable explanation is that the variation in light is due to pulsations of radiation in the star itself. Good reasons have been given from a study of the brighter Cepheid variables, for the conclusion that they represent a diameter, surface brightness and temperature of a particular degree, which varies only with the star's period of light-change. Their absolute magnitude as it is called may therefore be deduced from this feature, and if we accept this reasoning to its full conclusion, we can infer the distance of the stars and therefore of the globular clusters containing them. Not all of the globular clusters have been found to contain Cepheid variables, but some are veritable nests of them, that in Canes Venatici (Messier 3) containing 132,



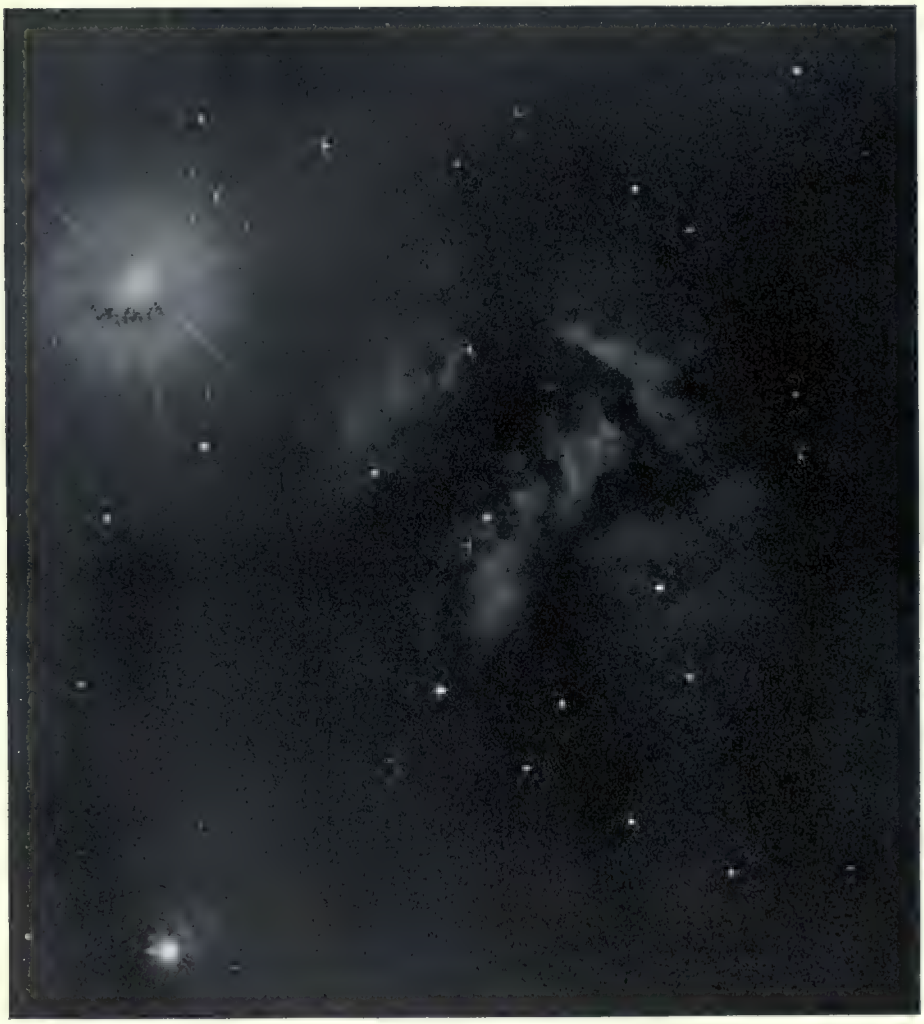
David Gill.

THE NEBULOUS REGION SURROUNDING η ARGUS.
PHOTOGRAPHED WITH THE VICTORIA TELESCOPE OF THE CAPE OBSERVATORY IN 1892.

This object, which lies in the southern sky, is one of the largest of the irregular galactic nebulæ. Sir John Herschel gives details of visual observations which point to variability in the part immediately surrounding the star. Photography will in time prove or disprove any suspected variability.

being one in seven of the total individualised stars studied in the photographs. The discovery of these variable stars is largely due to the work of Professor Bailey, of Harvard College Observatory.

The question of the distribution of the globular clusters in the sky has been the subject of important work in recent years. Mr. A. R. Hinks, while assistant at the Cambridge Observatory, pointed out that the globular clusters were concentrated with few exceptions in one hemisphere of the sky. He based his conclusions mostly on visual work, but these were confirmed by Melotte in an examination of the Franklin Adams photographs of the whole sky. These photographs do not show the fainter and smaller clusters definitely as such, and a certain number of these were added to the list by the systematic photographic work of the Lick and Helwân Observatories. These smaller clusters do not, however, affect the general conclusion that they lie almost entirely in one hemisphere. The pole of this hemisphere lies on the Galactic Equator (*i.e.*, the great circle of the Milky Way) in galactic longitude 320° in the constellation Sagittarius. It can hardly be a coincidence that this is in the same region as the greatest condensations of stars in the Milky Way. The star clouds of Sagittarius are so dense with stars that the individual star discs are inseparable on the Franklin Adams plates, while in the antapex (the region of the Milky Way 180° away in Auriga) the stars are comparatively scattered. The whole question has been discussed exhaustively by Shapley in the Mount Wilson Contributions, and he comes to the conclusion—which has a great deal to be said for it—that our Solar System is not near the centre of the Galaxy, as had previously been supposed, but that we are eccentrically situated in the proportion of four to one, the pole of the star cluster hemisphere being

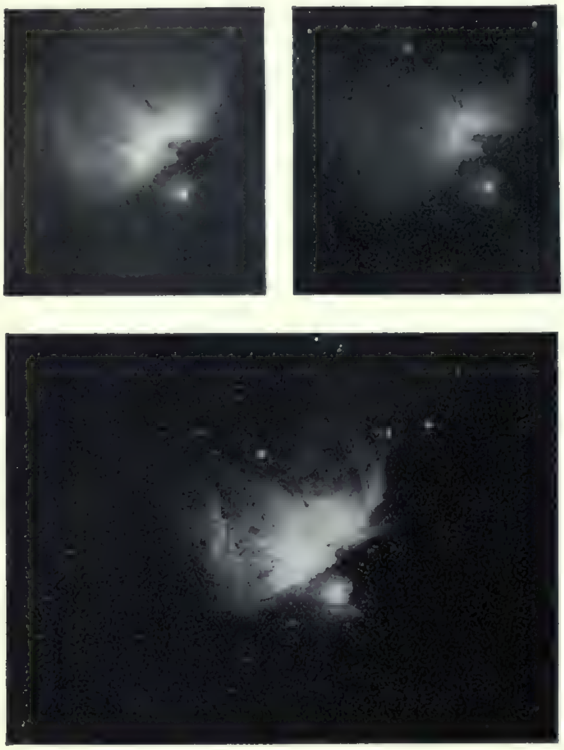


THE NEBULA H. V 28, N.G.C.2024 IN ORION. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

A cloud of gaseous nebulosity near the most easterly star in Orion's Belt, ζ Orionis. The rays of this star are not real, but diffraction effects formed by the supports of the 45 degrees plane mirror of the reflector. A star surrounded by nebulosity is also shown below.

THE GREAT NEBULA IN ORION (CENTRAL PORTION) PHOTOGRAPHED WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY, BY PROFESSOR RITCHEY.

This wonderful photograph shows the intricate convolutions of the nebulosity in surprising detail. The central part has been treated photographically so that its actual brightness is much reduced. The triangular-shaped patch involving the trapezium stars (θ Orionis) is in reality much brighter than the rest of the nebula, as can be seen from the small photographs in hydrogen light and the drawing. A bright star (blotted out by over exposure) lies in the separate patch of nebulosity below.



PHOTOGRAPHS OF THE ORION NEBULA WITH THE THIRTY-INCH REFLECTOR OF THE HELWAN OBSERVATORY.

The two upper photographs are images of the nebula in ultra-violet light at wave-length 3727, and in the hydrogen radiations respectively. The lower photograph is an unscreened exposure in which all the gaseous radiations appear. The difference between the two upper photographs is easily seen.

actually the direction of the centre of the Galaxy. This does not necessarily invalidate or conflict with the results of Kapteyn and Eddington, if we make the reasonable assumption that the two star streams are a more or less local phenomenon in the stars immediately surrounding us.

THE NEBULÆ.

It has been recognised for many years that the Nebulæ are to be classed in two great divisions, the galactic (gaseous and diffuse) and the spirals. The gaseous are again to be divided into two classes, the irregular and the planetary. The irregular gaseous nebulæ are usually found in and near the Milky Way in association with stars of a considerably higher temperature than the Sun, while the larger planetaries sometimes appear at a considerable distance from the Milky Way, and are almost invariably connected with stars of a still higher degree of temperature, in fact the nuclear stars of the planetaries are estimated to have a surface temperature of something like 30,000°C., against the Sun's 6,000°C. In these gaseous nebulæ we are indeed dealing with matter in its simplest forms, under conditions which can rarely be obtained in our terrestrial laboratories. Recent physical work in which this country has taken no mean part, has taught us a great deal of these ultimate forms of matter. Not so long ago, the atomic structure of matter was regarded rather as a theoretical speculation than as a reality, but to-day it is fully accepted, and the normal atoms of elements with nuclear positive charges and an equivalent number of negative electrons are arranged in a table known as the scale of atomic numbers. We must imagine each atom to consist of a positive nucleus surrounded by negative electrons, equal in number to the charges contained in the nucleus. The most primitive form of all is hydrogen, which has a nucleus of only one positive charge, with one attendant electron. The atomic weight of hydrogen is not unity as might be expected, but 1·008 when it is not in combination with other atoms. Next in order comes helium with two electrons, two positive charges in the nucleus, and an atomic weight of four, and so on. As the gases to be found in the nebulæ are in all probability those appearing in the first eight numbers of the atomic scale, a table of these elements is given below.

Element.	*Atomic number.*	*Atomic weight.*
Hydrogen	1	1·008
Helium	2	4
Lithium	3	6·94
Beryllium	4	9
Boron	5	10·9
Carbon	6	12
Nitrogen	7	14
Oxygen	8	16

But under the stress of extreme temperature conditions the atoms of the elements do not always retain their normal number of electrons, and the physical state known as ionisation is reached. This state is one in which the atoms have lost one or more electrons, although the positive charge of the nucleus remains constant. The element then gives a different spectrum, new lines appearing, and the original lines either weakening or disappearing altogether. We find in the spectra of the gaseous nebulæ many lines which cannot be identified with atoms of elements in their normal state. Two of these are usually very conspicuous, appearing in the blue-green part of the spectrum at wave-lengths 5007 and 4959. The former of these was the first to be observed by Sir William Huggins in 1864. At that time nothing was known as to the nature of the gaseous nebulæ, although it had been observed that they appeared of a greenish or bluish tinge in the telescope. Since his epoch-making discovery a great deal of work has been done, especially in America, in identifying the bright lines in the spectra of nebulæ, and in fixing the position of various unknown lines in the spectra. Hydrogen radiations were almost invariably found to be present, and helium was also identified. On the other hand, strong unknown lines also appeared, and it was thought until quite recently that these lines represented unknown gases in the same sense that helium was unknown until Sir William Ramsay identified the gas in the laboratory. But we know now from the formation of the scale of atomic numbers, and the great work of modern physicists at Cambridge and elsewhere, that there is no room in this scale for any more unknown gases of light atomic weights, and we must look in the direction of ionisation of known gases for the identification of these unknown lines. Fluorescence, or the degrading of ultra-violet light, has been also suggested as a possible cause. A start has already been made by Professor Fowler, at South Kensington. There is a well-known radiation appearing in planetary nebulæ at wave-length 4686 in the blue region of the spectrum which also appears in the spectrum of the hottest stars. Professor Fowler found that this radiation was given off by ionised helium, that is a helium atom still having two positive charges in the nucleus, but having lost one of its two electrons owing to great physical stress. It is significant that this form of helium only occurs near the star itself, thus showing that the ionisation only takes place where the radiation from the star is at a maximum. There are many other radiations which we cannot assign as yet to their proper elements, some strong, and others faint, but we will only deal with one which lies at wave-length 3727 in the ultra-violet part of the spectrum. This is, of course beyond the range of the eye, which

AN EARLY DRAWING OF THE ORION NEBULA, FROM THE HARVARD COLLEGE OBSERVATORY.

Compare this with the full-page photograph of this Nebula on page 551. The bright triangular portion is, however, better rendered than in the photograph.

THE DUMB-BELL NEBULA N.G.C.6853 IN VULPECULA. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

One of the largest and brightest of the planetary class. A central star, indistinct in this photograph, is well shown with shorter exposures, and it is from this star that the nebula possibly originated. These planetary nebulæ have great affinities with novæ in their later stages, and there is some reason for thinking that such a nebula as this marks the site of a past outburst. The elongated star discs are the result of a defect in following the object while it was photographed.

can only reach about wave-length 4000 in the indigo violet. As Sir William Huggins was the first to see the strong radiation in the green already mentioned, so he was the first to photograph this strong radiation in the ultra-violet in the Orion Nebula. It is not found in all nebulæ, and there is reason to think that it is not dependent on intense heat for its appearance, as it invariably extends to regions far removed from the stars in all the nebulæ where it is present. When a direct photograph of a nebula is taken at the focus of a reflector, the resulting image is a combination of all the gases contained in the nebula, and in the case of a small nebula photographed with a slitless spectroscope, separate images appear ranged along the spectrum in the various wave-lengths. We can thus judge of the distribution of the various radiations of known and unknown origin which

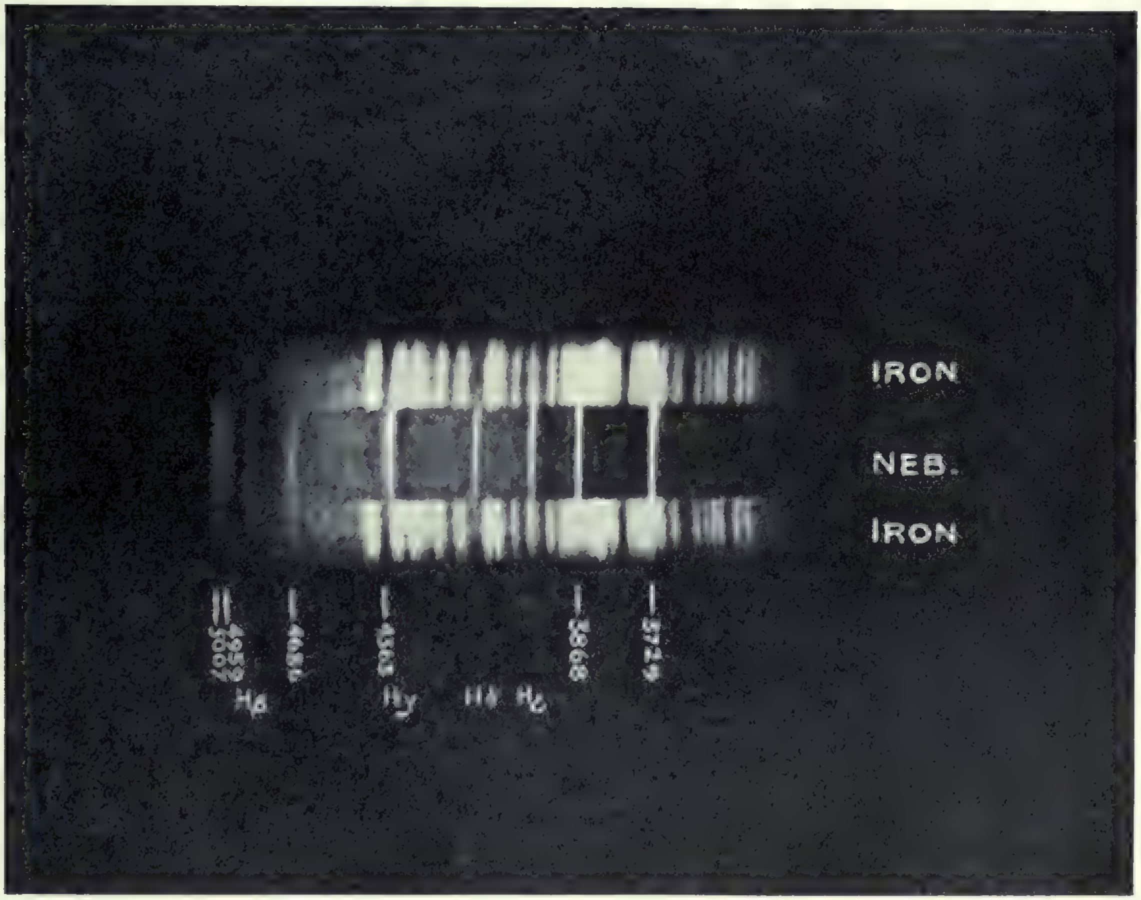


Photo by] [*Max Wolf.*

SPECTRUM OF THE DUMB-BELL NEBULA N.G.C.6853.

This is a gaseous emission spectrum on a faint continuous background. The hydrogen radiations Hβ, γ and δ are quite distinct as well as several radiations of unknown origin. The wave-lengths of the latter are given.

appear in the spectrum of a particular nebula. But when we are dealing with a large object of the angular size of the Orion Nebula, the images would overlap to such an extent that the slitless spectrographic method becomes valueless. Another method to ascertain the distribution of radiating gases has been devised to deal with the Orion Nebula and similar objects. The spectrum is already known to consist mainly of the two wave-lengths 5007, 4959; the hydrogen radiations in the blue and violet known as Hβ, Hγ, and Hδ, and the strong single radiation at wave-length 3727. By using suitable colour filters and plates, the first two divisions can be sufficiently isolated to say that the negatives obtained represent the images in λλ5007, 4959, and the hydrogen radiations. The question of isolating the radiation λ3727 is, however, more difficult. Among the aniline dyes, one, known

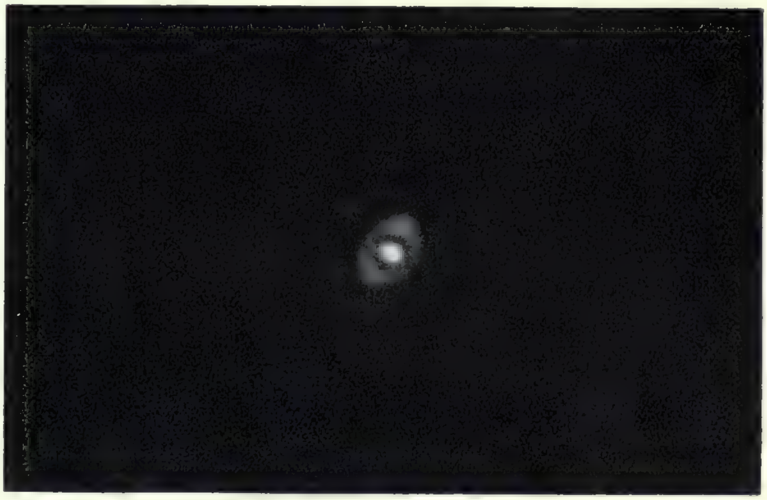
THE HELICAL NEBULA N.G.C.7293 IN AQUARIUS. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

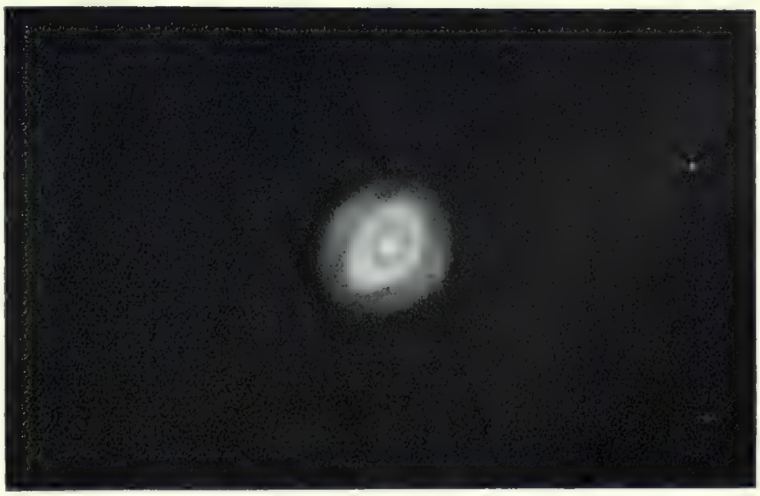
This is a gaseous nebula of the planetary class, based on the central star, which is of very high temperature. It possibly owes its helical appearance to two successive outbursts, as two over-lapping shells of gas are present.

by the rather imposing title of nitroso-di-methyl aniline, allows the ultra-violet part of the spectrum to be transmitted, at the same time considerably weakening the blue in the visual spectrum. But a glass containing nickel oxide makes a much better filter for the particular radiation λ3727, for it cuts out all the visual spectrum except the extreme red, and transmits almost three-quarters of λ3727. This was the method used by the writer to investigate the distribution of the three groups in the Orion Nebula. Two of the photographs illustrating the difference between the hydrogen and λ3727 radiations are reproduced on page 552. We can see at once that the hydrogen image is neither so widely distributed nor so bright in the outer regions as the other, and certain differences of detail can also be distinguished. This quite clearly proves that the great photographic brilliancy of the Orion Nebula is not due to hydrogen so much as to the strong radiation λ3727 of unknown origin. What element it actually represents is one of the most interesting questions the astrophysicist has to deal with, for it must be a gas of extraordinary lightness to be swept away to such an enormous distance from the stars involved in the nebula, and yet hydrogen is the lightest gas possible, consisting, as it does, of one positive charge and one negative electron. The other unknown radiations—λλ5007 and 4959 in the green—are strongest in the central portions of the nebula, and there is no difficulty in assigning these probably to an ionised form of one of the heavier gases—carbon or nitrogen. Certain lines in the spectra of nebulæ have, indeed, already been identified with these elements in their normal form.

The whole region surrounding the Orion Nebula contains vast clouds of non-luminous matter. An excellent example of this is given in the wonderful photograph of the region near the star ζ Orionis, reproduced on page 47. Here one-half of the field of the photograph is almost devoid of stars, those that do appear being comparatively bright with patches of nebulosity. This lack of stars is evidently owing to an extended cloud of obscuring matter, which effectually blots out the stars behind. Along its edges appear filaments of nebulosity with a conspicuous projection, like a blot of ink, also illumined round its edge. These filaments represent the edge of the cloud, and we can infer without much doubt the existence of many brilliant stars in and beyond the cloud which are totally invisible to us, from which the light is transmitted, just as the edge of a terrestrial cloud is lit up by the Sun behind. Beyond this illumined edge we look into the clear regions of space, where the fainter and more distant stars are seen in the usual profusion. There are many of these dark obscuring clouds in and near the Milky Way, to which attention was first drawn by the American astronomer, E. E. Barnard, who obtained surprising results with a camera fitted with a large lens of short focus used in the early days of photography for portraiture. Of recent years special attention has been directed to these areas by H. N. Russell and Hubble at the Mount Wilson Observatory, and the interdependence of stars and nebulosity strikingly confirmed. A question of exceptional interest is the origin and nature of these gigantic clouds of dark matter. In the early days of the present century, Professor J. H. Poynting, Professor of Physics at the Birmingham University, dealt with the pressure exerted by a brilliant light source on finely divided matter in the form of dust, and he showed that if the particles were small enough to be comparable in size with a wave-length of yellow light,

the light pressure would be greater than the gravitational force, and the particles would then be swept away from the light source if the latter were of the same order of brilliance and surface temperature as the Sun. He applied this principle to the sweeping away of the cometary matter from the Sun, and he thus explained the well-known fact that the tails of comets always extend in a direction away from the Sun. As both the light pressure and the gravitational force vary as the inverse square of the distance, it follows that if once the light source is brilliant enough to overcome the gravitational force it will continue to do so, as long as the size of the particle is small enough, and it is not shielded by others. This repulsive force inherent in the stars very much increases with the temperature, in fact it varies as the fourth power of the temperature, so that the pressure of light, or rather as it should be put, radiation pressure in stars such as those in Orion with a spectrum of hydrogen and helium absorption lines is increased to 100 times that of gravitational attraction. It is clear that this supplies us with a quite adequate explanation for these cosmical clouds of dark matter. The total radiation pressure from stars and star clusters in the denser parts of the Milky Way would be quite enough to account for minute particles being swept away from the neighbourhood of the stars into interstellar space where they would tend to congregate and produce the great clouds of dust which we know exist as dark nebulæ. Where a bright star is near the cloud, the light of the star illuminates that part of the cloud nearest to it, and we get a nebula of irregular form surrounding the stars. A particularly interesting case of a dark nebula, associated with stars and bright nebulosity, is afforded by the region of the variable star R Coronae Australis in the southern hemisphere of the sky. A photograph of this region is reproduced on page 548. Here we have not only an irregularly variable star, but also a variable nebula attached to it, something similar in appearance to a comet's tail. This variable nebula, observed first of all by Dr. Schmidt at Athens forty years ago, has been the object of a long series of photographic observations by Mr. Knox Shaw at the Helwân Observatory in Egypt. When the light of the star sinks to a





THE PLANETARY NEBULA H. IV 27, N.G.C.3242 IN HYDRA. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

These two exposures of one minute and ten minutes respectively show how the inner and brighter details are obscured by over-exposure. The bright nucleus is a star of high temperature. There is a distinct suggestion of radiation pressure in the dusky ring surrounding the nucleus.

minimum, the light of the nebula fades practically to extinction. When it rises to a maximum, the nebula gradually becomes visible again, but it never assumes exactly the same aspect as at previous brightenings. We cannot be far wrong in concluding that the star is passing through the cloud of dark matter which is already known to exist from the almost entire absence of stars in the region, and that its variability is due to its encounter with the denser portions of this cloud. As the spectrum of both the star and the nebulosity is of the same type, including bright hydrogen lines, it is practically certain that the nebulosity becomes visible by reflection from the star, and in the gradual extension of illumination from the star, we are observing the passage of light from the star at the rate of 186,000 miles a second. This gives us a fairly reliable estimate of the distance of the object which Hubble puts at 300 light-years. Although the edge of this cloud is not illuminated in the same way as that near ζ Orionis, yet its limits are readily seen from the number of faint stars, including a star cluster which appears on the right-hand top corner of the plate.

[G. W. Ritchey.

THE CRAB NEBULA N.G.C.1952 IN TAURUS. PHOTOGRAPHED WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

This gaseous nebula is of a type intermediate between the planetaries and the irregular, and contains a central star of the Wolf-Rayet type. Its filamentous character is well seen in the photograph. Investigations at Mount Wilson have suggested a probability of radiating motion in this nebula.

We will now pass on to the other class of gaseous nebulæ—the planetaries. Here we have a central star surrounded by a luminous disc or ring usually of very complicated structure. Illustrations of two of the best-known examples of these types have already appeared—the Owl Nebula (page 135), and the Ring Nebula in Lyra (page 127). There are two others of this class which are of even larger diameter. One is the so-called

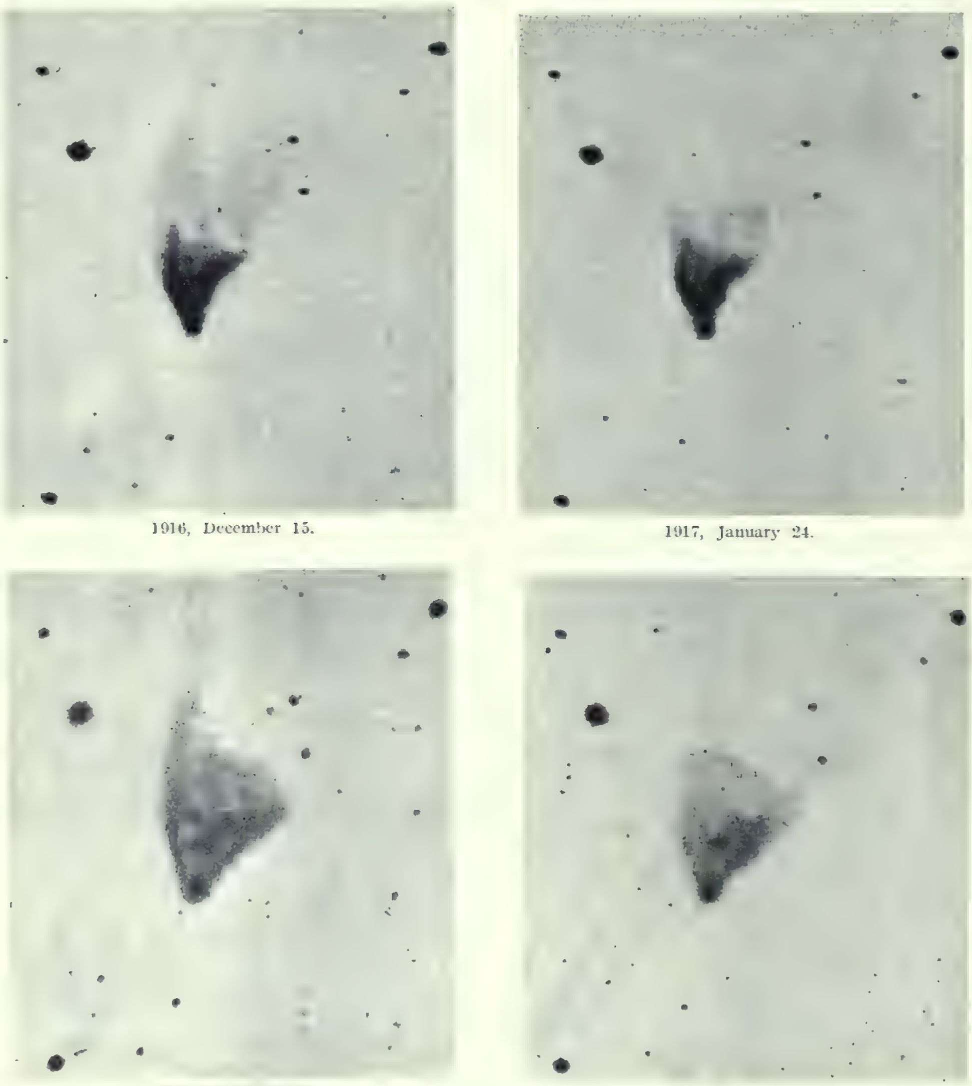
THE ANNULAR NEBULA H. IV13, N.G.C.6894 IN CYGNUS. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

This is not really a ring, but a hollow sphere of radiating gas, the ring effect being due to perspective, and the heaping up of luminous gas in the line of sight. The central star is thought to be the origin of the nebula, and like all central stars of the planetaries, it is of very high surface temperature.

"Helical" Nebula in Aquarius, which is shown on p. 556 from a photograph taken at the Lick Observatory, the other is the well-known "Dumb-bell" Nebula in Vulpecula. There is another nebula bearing a resemblance to the planetary class in some respects, and to the irregular gaseous nebulæ in others, which is known as the "Crab" Nebula. It would be a mistake to suppose that the "Ring" Nebulæ are really annular in form; if they were, we should not see them all as circular or slightly elliptic rings, but their normal appearance would be "two to one" ovals, owing to the law of average distribution of angles. They must actually be shells of luminous gases, the annular aspect being the result of perspective and the heaping up of luminous material in the line of sight. All ring nebulæ show some filling up of the ring when long exposures are given, and everything points to the constitution of these objects as being spherical or elliptical shells surrounding the central star. There is thus no real difference between the "ring" nebulæ and the planetaries, the latter often consisting of many rings superimposed. The actual scale of these objects is sufficiently imposing; at the least, the larger ones must exceed the orbit of Neptune several times, and until recently we knew nothing of the causes which would keep these enormous bubbles of gas in being. The extended researches of the Lick Observatory on planetary nebulæ have, however, at last given us the clue. Mention has already been made of the high temperature of the central stars in the planetaries. They are all of the class known as Wolf-Rayet, or "O" type stars, their spectrum being remarkable for the presence of ionised helium usually as bright bands, but sometimes as absorption bands. Under the influence of these transcendant temperatures, disintegra-

tion of the more complex atoms to simpler forms probably takes place, and the radiation pressure sweeps away these gases from the neighbourhood of the stars in the same way as we have seen that fine dust is expelled. When a certain distance is reached, depending on the surface temperature of the star, and the atomic weight of the gases, an equilibrium between gravitational force and radiation pressure is set up, and the result is a more or less stationary shell of gas, shining probably by the excitation of negative electrons which the star is perpetually pressing into the surrounding space.

A confirmation of this view is afforded by the character of the lines in the spectrum of one of the planetary nebulæ. These lines were photographed under high dispersion with the giant refractor of the Lick Observatory, and under magnification are seen to be broadened out in the middle and slightly curved in opposite directions at each end. If we are to interpret these features on the Doppler principle, then the broadening of the lines means that the gases are both approaching and receding, coupled with a slow rotation of the gaseous shell. We thus have very decided evidence that some of the planetary nebulæ are still expanding. This brings us to a comparison of these objects with temporary stars or novæ. The general character of novæ is dealt with in the next chapter of this work, but there is so much in common between these and the planetary nebulæ that mention must be made of them here. When the outburst of a nova first takes place, the spectrum is



1916, December 15. 1917, January 24.

1919, December 27. 1920, March 23.

HUBBLE'S VARIABLE NEBULA N.G.C.2261 IN MONOCEROS.

PHOTOGRAPHED WITH THE THIRTY-INCH REFLECTOR OF THE HELWAN OBSERVATORY.

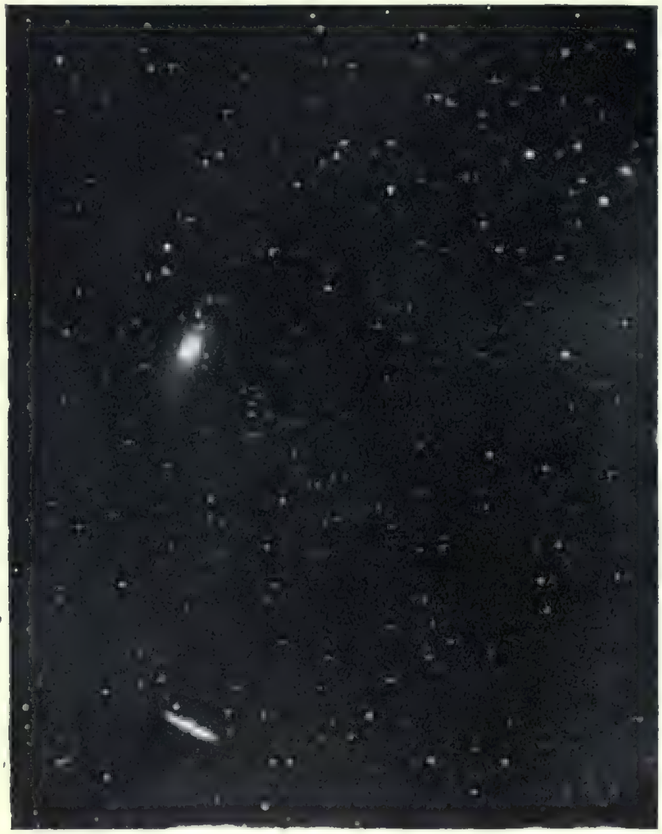
This nebula is attached, rather like a comet's tail, to the variable star, and is similar to the variable nebula attached to R Coronae Australis. The four photographs (in negative) show the variation in appearance of the nebula very plainly.

[*G. W. Ritchey.*

NUCLEUS AND CENTRAL PORTION OF THE ANDROMEDA NEBULA, FROM A PHOTOGRAPH OBTAINED AT THE MOUNT WILSON OBSERVATORY WITH THE SIXTY-INCH REFLECTOR.

This is the largest spiral nebula (in angular size) in the whole sky, and covers two square degrees ; it is also in all probability the nearest. The two spiral arms issue from two diametrically opposite points in the nucleus, which greatly increases in brilliancy to a central point. It was in this nucleus that a temporary star of the seventh magnitude appeared in 1885, but the stars appearing in the photograph are galactic stars and probably have no connection with the nebula.

crossed by absorption lines which are usually assigned to stars of a type between the helium stars and the Sun. In addition, bright lines of hydrogen appear much broadened, and indicating high velocities of recession and approach. The earlier stages of spectra are very complicated and difficult to explain, but ultimately, as the purely stellar spectrum gets fainter and the light of the star diminishes, so a gaseous spectrum resembling those of planetary nebulæ makes its appearance. In the case of Nova Aquilae III, the brilliant new star of 1918, an expanding gaseous disc has made its appearance, and this nova is now a minute planetary nebula. We have, therefore, conclusive evidence that a nova may sometimes actually pass into the condition of a planetary nebula. A very significant feature in the latter stages of novæ is the development of the "O" type of spectrum as the star fades. This must mean, actually, a higher surface temperature of the star than when it was at its greatest brilliancy. It seems therefore that the first effect of the outburst must be a great development in the diameter of the nova rather than an extreme surface temperature, as the type of spectrum shows that this comes afterwards in the gaseous stage. The view that the planetary nebulæ had their origin in outbursts of novæ in past ages, although by no means universally accepted, is the only one at present which gives a rational explanation of their origin. An objection has been raised that if this were so, we should expect to find many more planetary nebulæ than we actually do, for novæ are by no means so rare as a list of the brighter ones only would lead us to infer. The answer to this is that the planetary aspect can only exist with a central star of the highest scale of surface temperature, and a corresponding radiation pressure. If and when the temperature falls below a temperature of about 15,000°C., the radiation pressure would not be sufficient either to keep the shells of gas in equilibrium or to illuminate them, and the nebula would contract and finally disappear. This is probably one of the reasons why many planetary nebulæ have only minute discs, or in some cases no apparent discs at all, being classed as planetaries only because of the gaseous type of spectrum they give. At any rate, diameter is not the only criterion of distance in such cases. We may go further, and question whether the other gaseous nebulæ did not have their origin in past outbursts. The Nebula in Orion has every appearance of being swept away from the central region containing the stars of the trapezium (θ Orionis), and possibly the enormous masses of hydrogen and other gases which now form the nebula had their origin in the stars themselves. In the early days of nebular observation and of Laplace's Nebular Hypothesis, it was believed almost universally amongst astronomers that the nebulæ generally were the primeval material from which the stars and planets were evolved. But

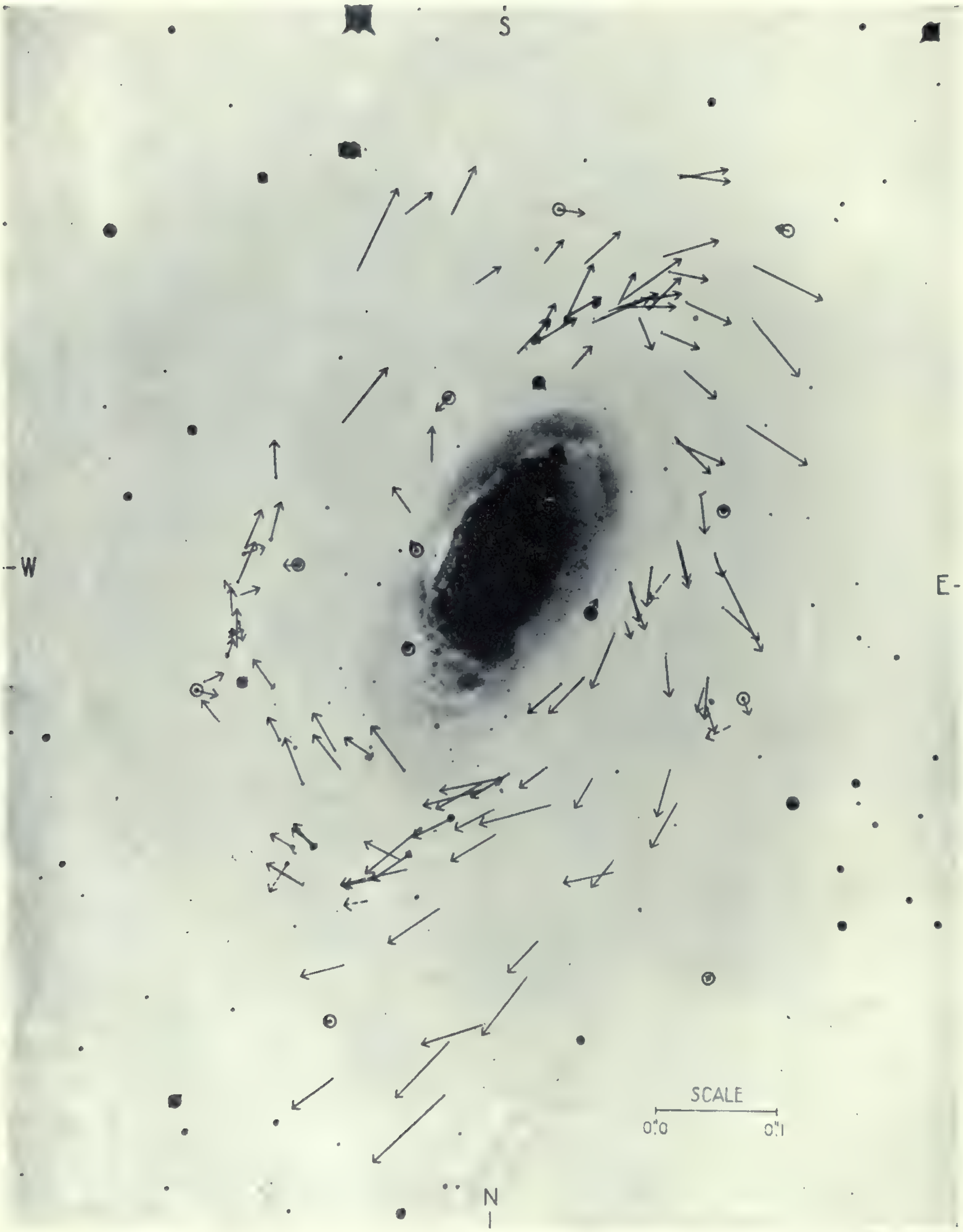


A SMALL SCALE PHOTOGRAPH OF THE REGION CONTAINING THE TWO SPIRAL NEBULÆ, M.81 AND M.82, IN URSA MAJOR, BY DR. ISAAC ROBERTS.

The hazy disc on the top right-hand side is a good example of the "globular" nebulæ which are probably the nuclei from which the spiral arms are formed.

THE SPIRAL NEBULA M.81 (N.G.C.3031) IN URSA MAJOR. PHOTOGRAPHED BY G. W. RITCHEY WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

This is a good example of the partially condensed type of spiral, the outer regions of the spiral arms being broken up into bright nodules, some of which have an almost stellar character. Dark irregular bands of absorbing matter appear on one side of the nucleus, but not on the other. This is a usual characteristic of spirals inclined at angles under 30 degrees to the line of sight and is most probably an indication that this side is towards us.



[*Van Maanen.*

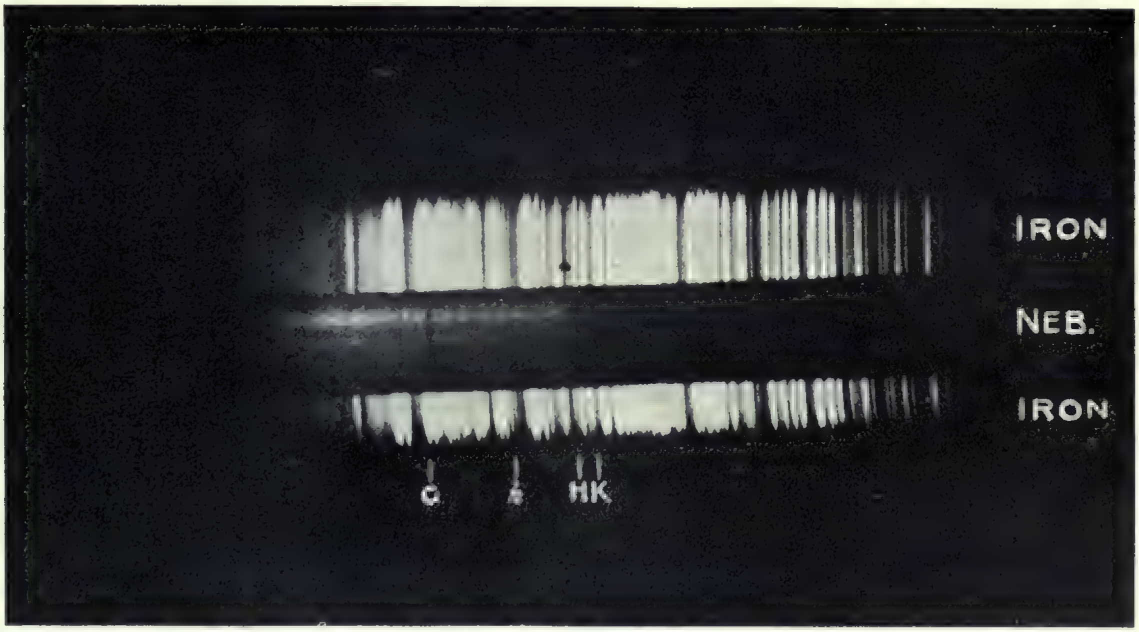
DIAGRAM OF THE SPIRAL NEBULA M.81, N.G.C.3031, SHOWING MOTION AND DIRECTION OF CONDENSATIONS IN THE SPIRAL ARMS.

The length of the arrows indicates the amount of motion in one year. The direction of motion is obviously outwards from the nucleus along the spiral arms, which must ultimately drain the matter composing the nucleus. The dots in circles are the comparison stars which were employed for finding the nebular displacements. The scale marked (0·1 of a second of arc) is the scale of the arrows and not of the nebula itself.

all recent research is in favour of the exactly contrary hypothesis, that the gaseous nebulæ are the product of intense temperature conditions which cannot arise apart from stars or other bodies giving a stellar type of spectrum. The origin of stars and planets is much more likely to have been local concentrations in dust clouds. This does not really carry us much further, for these dust particles must in themselves have been the product of the elements such as we know are to be found everywhere in the visible universe. We are thus led round a circle which has no beginning and no end, a fundamental difficulty which it is very improbable will ever be overcome by the human mind.

THE SPIRAL NEBULÆ.

Sir William Herschel noticed in his telescopic sweeps of the sky that nebulæ appeared to concentrate in regions remote from the Milky Way and surrounding the North Galactic Pole. But these nebulæ were of a totally different type from the great irregular nebulæ, such as that in Orion, and the planetaries. They were compact, oval or round in shape, and usually much brighter up to a point in the



SPECTRUM OF THE NUCLEUS OF THE SPIRAL NEBULA M.81, N.G.C.3031. PHOTOGRAPHED BY PROFESSOR MAX WOLF, OF HEIDELBERG.

The type of spectrum is similar to that of the Sun; the two lines of hydrogen G and *h* (Hγ and Hδ), and the two calcium lines H and K are conspicuous. The comparison spectrum on each side is produced by a spark discharge, and the number of lines makes it easy to measure the position of the nebular lines.

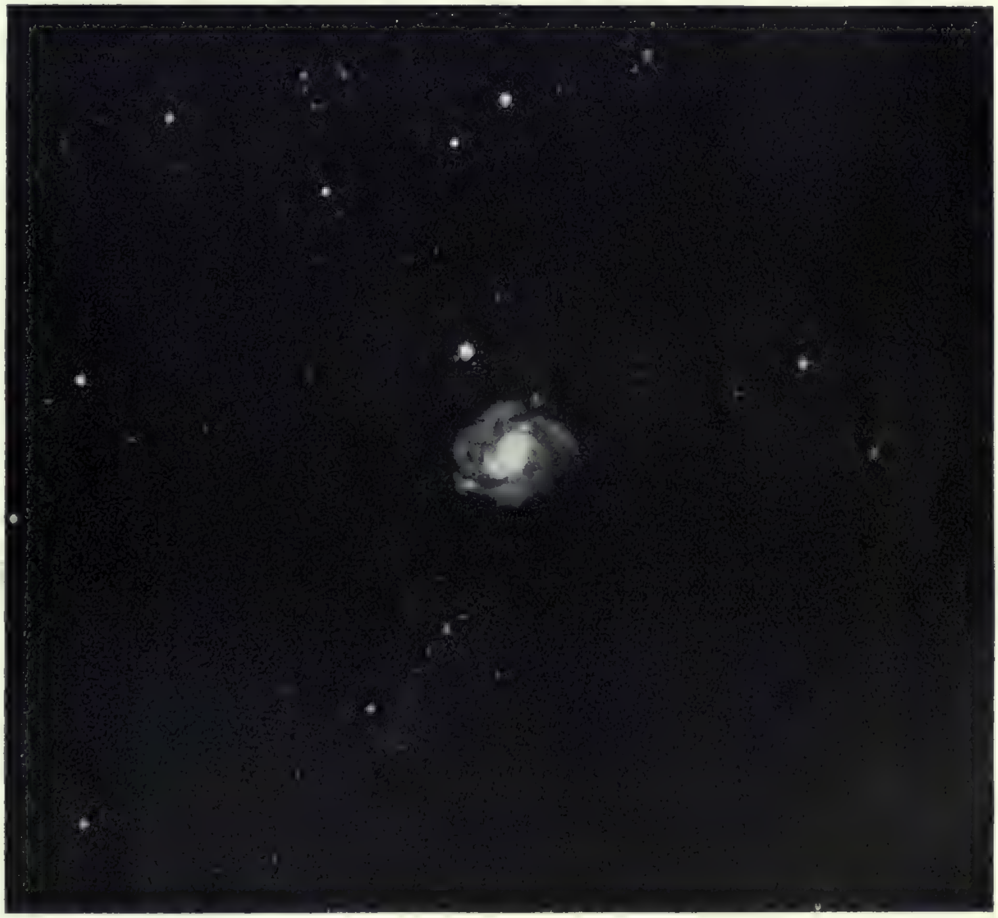
centre of the ellipse or circle. Others were much elongated, and often attended by what appeared to be another nebula, parallel in direction, sometimes of equal size, and sometimes smaller. Many and curious were the drawings and engravings of these objects appearing in the time of Sir William and Sir John Herschel. They had no idea at all what the real character of these extraordinary objects was, nor can it be said that we have any very certain idea yet, although our knowledge of them has been enormously amplified by photography. Observers were led away by the supposed analogy of globular star clusters to assume that many of these objects could be resolved into stars if sufficient optical means were employed. Where glimmering points of light were suspected, such nebulæ were described as "resolvable." But it is only right to add that the existence of nebulosity which obviously could not be resolved into stars was fully recognised by both Sir William and Sir John Herschel: Sir William described it as "a luminous fluid the nature of which is unknown to us." In the 'sixties of the last century, nebular observation was taken up very enthusiastically by

Lord Rosse and his assistants. A parabolic mirror of speculum metal, six feet in diameter, had been constructed and mounted at Birr Castle in Ireland. The mounting was very crude according to modern standards, and yet one of the most important discoveries ever made in nebular observation was effected by the light grasp of this instrument. Lord Rosse announced that he had observed a spiral arrangement surrounding the nuclei of certain nebulæ, and he also thought that in some cases he had resolved these spiral arms into wreaths of stars. The first announcement has been fully corroborated by photography, but the second has not, although there is a very natural explanation of his observations to which we shall refer later. It was to Dr. Isaac Roberts, an English amateur, that we owe the photographic demonstration of the reality of the spiral formation of certain nebulæ. By long exposures up to three hours a great number of the nebulæ lying outside the Milky Way were found by him to be spiral in character. Keeler at the Lick Observatory found on the plates containing the large spirals many small nebulæ of round or oval form, which he concluded were also spirals at such distances that their spiral form could not be identified. This led him to make certain calculations as to the number of spirals in the whole sky, and by taking certain regions

THE "EDGE-ON" SPIRAL NEBULA N.G.C.891, PHOTOGRAPHED WITH THE ONE-HUNDRED-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

This nebula is ten minutes of arc in total diameter, and the centrally situated band of absorption shows that its plane is remarkably near the line of sight in its inclination. Small nebulous condensations appear in this band evenly spaced apart if we allow for the effect of perspective. This is in accordance with Dr. Jeans's theoretical work, which postulates such a breaking up of the nebulous matter into nodules. The fact that they appear along the absorption band means that the dark matter lies nearer to the nucleus.

as representative and counting the number of nebulæ, small and large, he arrived at the enormous number of 2,000,000. This result is certainly a great over-estimate, for it is now known that the distribution of spiral nebulæ is very unequal in different parts of the sky, and one-quarter of the galactic sphere contains only about a dozen of these objects. Besides this, there is no good reason why all the nebulæ appearing on the plates should be classed as spirals, although they are no doubt not of the gaseous emission class. They often appear as small structureless round or oval formations, with a concentration of light in the centre, and we should probably be much nearer the mark if we considered them to be the nuclei from which spiral arms have in some cases been evolved. Although the term "globular" nebulæ is as old as the Herschels' time and was sometimes applied to globular clusters, it has now been adopted as a good description of these nuclear nebulæ. Among the small round and oval nebulæ there often appear one or two long thin objects usually broader in the middle. These are small examples of the spiral nebulæ in which the plane of the spiral arm lies in the line of sight; they are therefore sometimes called "edge-on" spirals. The appearance of this thin plane in the line of sight carries with it the conclusion that the spiral arms have developed in such cases. The variation in apparent size between one spiral nebula and another is very great. The largest in the sky is the Great Nebula in Andromeda, which is 135′ × 45′ in diameter, and covers over two square degrees. The smallest range down to 30″, and possibly less, and we must take the angular diameter of the spirals broadly as a criterion of distance in the same way as the magnitudes of stars are taken as a rough criterion of distance. A comparison of an old drawing of the Andromeda Nebula made from visual



THE SPIRAL NEBULA N.G.C.1068. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

This spiral nebula is remarkable for its spectrum, which shows strong emission lines of hydrogen and other gases, superimposed on a stellar type of spectrum. The displacement of the bright lines corresponds to the enormous velocity of 1,800 km./sec.

observations with a photograph taken in America with the twenty-four inch reflector of the Yerkes Observatory has already appeared on page 55. The photograph makes a beautiful picture and we see at once how the dark lines which seem to have no meaning in the drawing, are shown to have a very definite meaning in the photograph. Two other smaller nebulæ appear on the plate ; one of these is a good example of the globular nebulæ. This great nebula is unusually close to the galactic equator, and a number of stars appear in the photograph which are undoubtedly of galactic origin, probably having no connection with the nebula. We must not think, however, that the Andromeda Nebula ever actually appears like the photograph reproduced, either to the eye or in a photographic negative. The details are all faithfully reproduced both in dimensions and position, but their brightness has been enormously exaggerated by photographic manipulation, so that the actual light values brought out on the negatives have more or less disappeared. The outer regions are in reality excessively faint, so that a long exposure is necessary to make them visible at all on a rapid plate : on the other hand, the central portion is quite bright, and becomes over-exposed before the outer regions affect the plate. The actual nucleus is circular in form with a great brightening up to a central point ; a photograph of the nucleus and central regions of the nebula is given on page 561. The nebulosity of which the nucleus and all except the outer whorls are composed is filmy and structureless ; both to the eye and on the photographic plate no difference can be discerned between this type and the gaseous nebulosity. The real difference lies in the type of spectrum, for in the Andromeda Nebula, there are no emission lines of hydrogen or other gases, but a continuous spectrum of stellar type crossed by dark absorption lines similar

THE NEBULA H. I 163 SEXTANTIS, N.G.C.3115. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

The largest example in the sky of the lenticular nebulæ which are required by Dr. Jeans's theory of spiral development. It is seen edge-on, as if in section, and no spiral arms have yet been produced, although from its outline it is apparently at the critical stage of rapid rotation.

THE STARS FOR DECEMBER

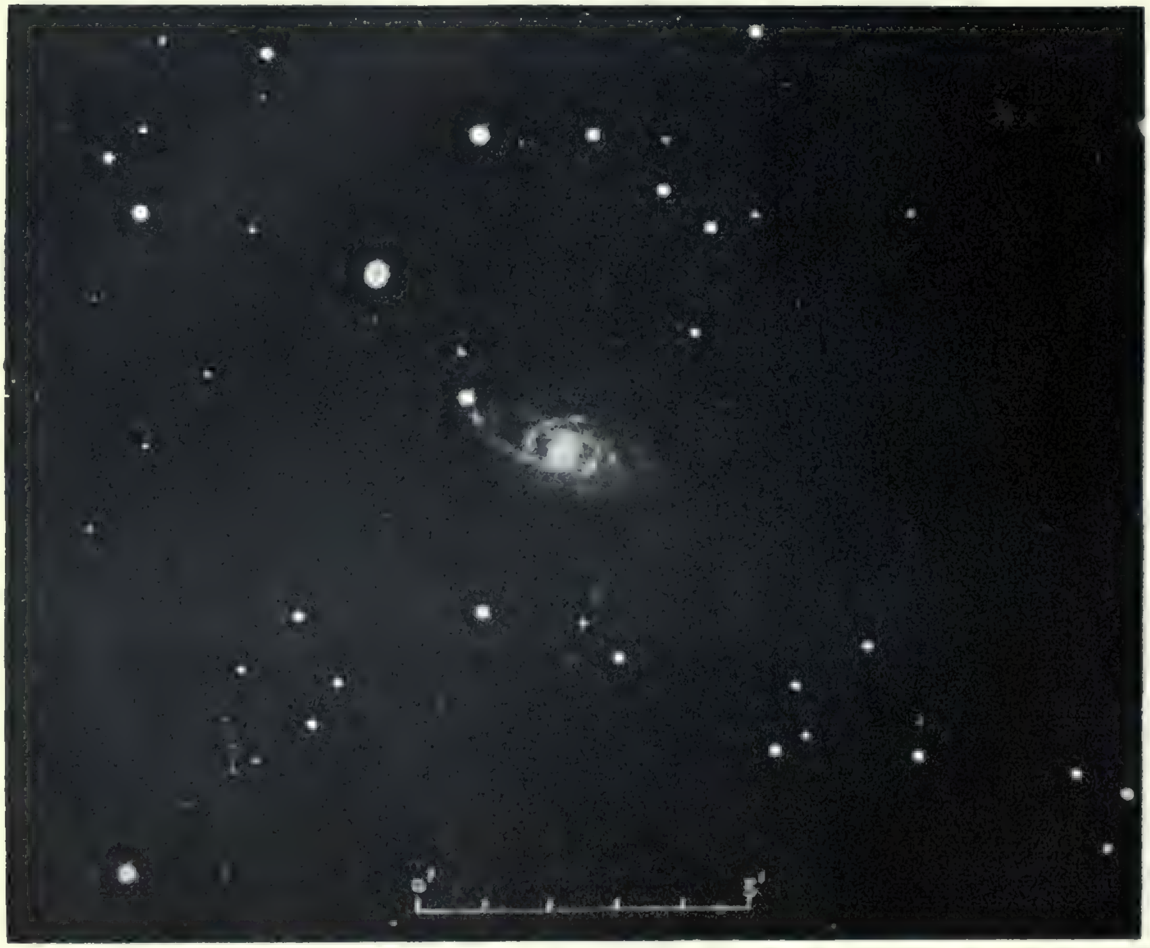
Our plate shows the aspect of the sky as seen, looking North and South, from Westminster Bridge; but the positions of the stars will be practically the same for any place in the latitude of Great Britain.

The constellations will appear in the positions shown on December 1 at about 11.30 p.m. (Greenwich Mean Time)

THE SPIRAL NEBULA M.64 (N.G.C.4826) IN COMA BERENICES. PHOTOGRAPHED BY PROFESSOR RITCHEY WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

The best example so far photographed of the uncondensed spiral nebulæ. The central portion has a remarkable area of absorbing matter, probably lying between us and the nucleus, which was noticed by Lord Rosse. It is doubtful if the bright patches are condensations as the rest of the nebula is quite structureless. The general appearance of this nebula is strikingly suggestive of luminous dust, and is thus in agreement with the hypothesis that the spiral nebulæ originated in dust clouds expelled from the Milky Way by radiation pressure. There is an extraordinary dearth of stars in this region.

to those in the solar spectrum. In the outermost regions a different type of nebulosity appears: it is broken up into small nodules and irregularities, and has been called the granular type. These are very much fainter than the nuclear regions but are definitely brighter than the external structureless nebulosity, and they are obviously condensations in the cool outer matter of the nebula rendered visible owing to the heating effect of such condensation. These in turn show a tendency to form clusters of condensations, and it is quite certain that they are in an unstable state, for what seem to be faint novæ make their appearance from time to time in these outer regions. We have no evidence at all as to the spectra of these novæ; all we know is that what appear to be stars appear and disappear, and we must not push analogy too far in supposing they are of the galactic nova type which develop into



THE SPIRAL NEBULA N.G.C.151. PHOTOGRAPHED WITH THE THIRTY-INCH REFLECTOR OF THE HELWÂN OBSERVATORY.

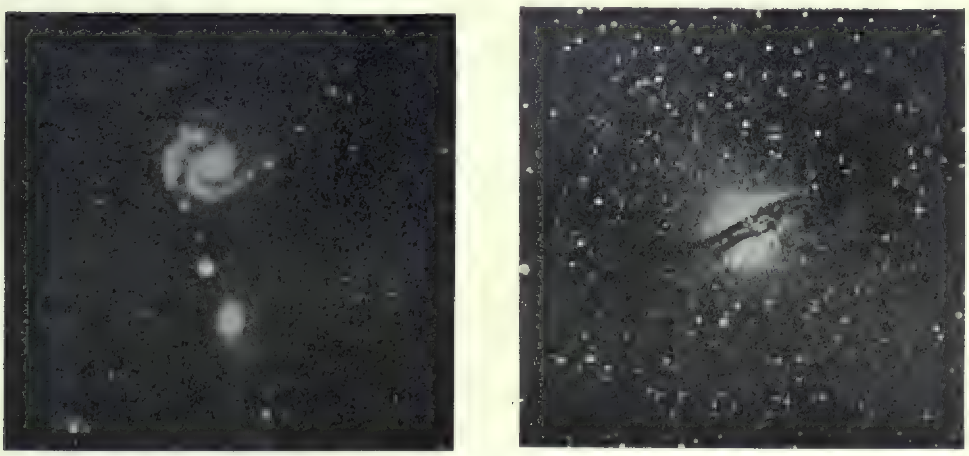
This spiral seems to have developed in more than one plane, and consists of a bright small nucleus with filamentous arms. These nebulæ photographed at the Helwân Observatory are all too far south for observation in this country.

Wolf-Rayet stars. All the novæ which have appeared in the Andromeda Nebula are not faint, for quite a bright object of the seventh magnitude was discovered in 1885 near the nucleus. It was most unfortunate that photography as applied to the telescope and spectroscope was so little developed at that time, for we should otherwise have got some extremely interesting information as to the constitution of the novæ appearing in spirals. The spectrum was only observed visually, and the records of its appearance to the eye are very vague and unsatisfactory, but all the observers agree that the spectrum was not of the normal bright hydrogen type, although several bright bands of unknown origin were suspected.

No nova has since appeared in spiral nebulæ to equal this, and it is strangely overlooked in discussions on the distant universe theory of the spirals, which has been put forward so strongly by Sir David Gill and others. If the Andromeda Nebula were a distant galaxy comparable in size with our own, we could not put its distance at anything less than 200,000 light-years. But what order of real magnitude are we to assign to a star that appears to us as of the seventh magnitude at so remote a distance? No nova ever observed would be in the least comparable to such a transcendant brilliancy, and its total and rapid disappearance would be still more strange. Mention has already been made of the solar type of spectrum which is given by the Andromeda Nebula. What the true interpretation of this type is in the spirals we cannot definitely say, but Dr. J. H. Jeans has treated the problem of spiral development mathematically as a gaseous one, and there is no physical reason for the assumption often made that an absorption type of spectrum is necessarily non-gaseous. In a few examples, such as N.G.C.1068, the type of spectrum is more like that of the planetary nebulæ with bright emission as well as absorption lines. The absorption type has, however, led some astronomers to the conclusion that all the spiral nebulæ are distant galaxies of stars, although the nebulosity is textureless, and utterly unlike the photographic appearance of a close assemblage of minute stars such as we often find in the Milky Way. To get a good photographic impression of the spectrum of such a faint object as the Andromeda Nebula, it is necessary to make very prolonged exposures up to eighty hours, spread over several nights. The remarkable feature of most of the photographed spectra of spirals is the displacement of the dark absorption lines from their normal positions. As a rule this displacement is towards the red, which normally would be

LORD ROSSE.

Portrait of Lord Rosse, whose six-foot reflector, at Parsonstown, first revealed the spiral character of certain of the nebulæ.



(1) THE SPIRAL NEBULA N.G.C.5128; (2) THE NEBULA N.G.C.5247. PHOTOGRAPHED WITH THE THIRTY-INCH REFLECTOR OF THE HELWÂN OBSERVATORY.

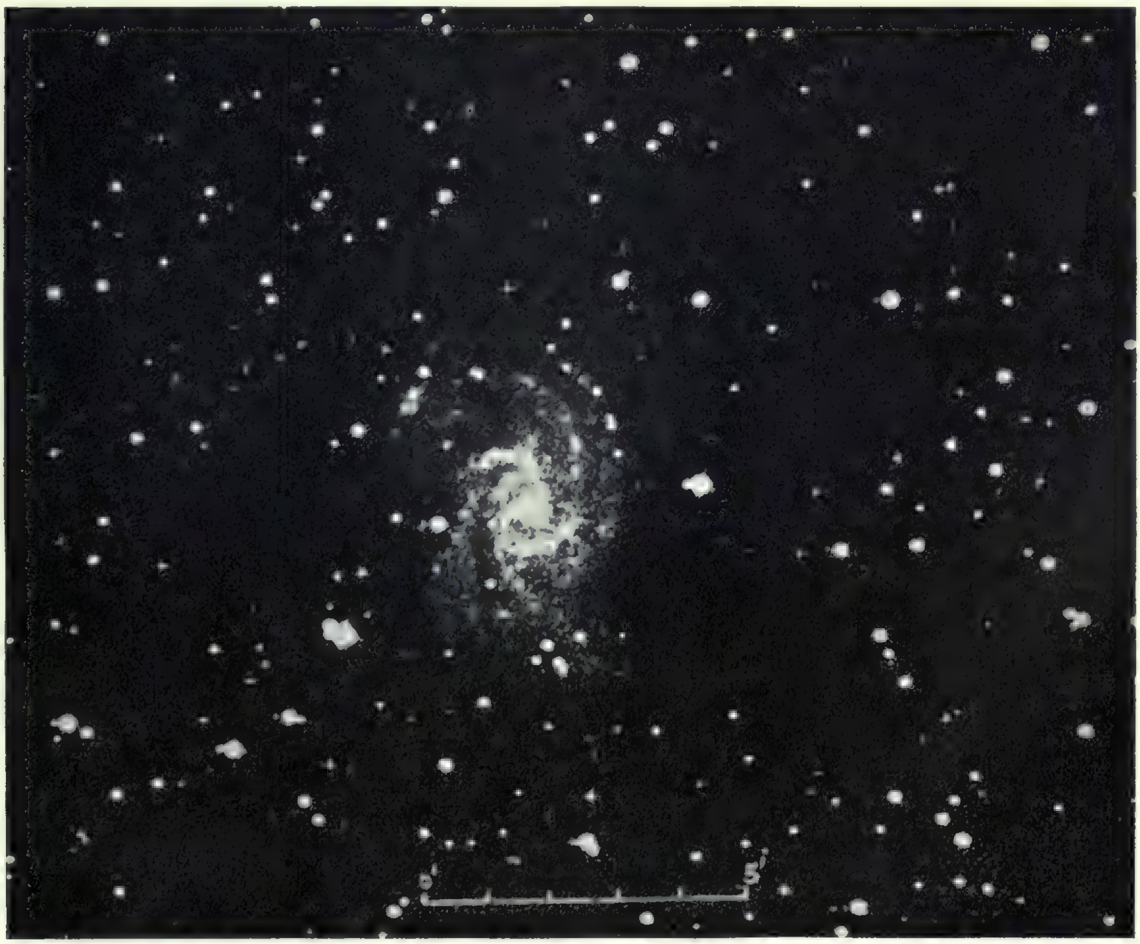
The first of these is an embryo spiral which has not developed very far. Below is an elongated globular nebula, the elongation being in the direction of the spiral. It is quite probable that the globular nebula will also develop spiral arms in time. The second is a nebula which may be either of the gaseous or the spiral class, having a dark band of absorbing matter. If it is the latter, it is the largest of the apparently globular nebulæ in the sky.

THE SPIRAL NEBULA N.G.C.5194/5 IN CANES VENATICI. PHOTOGRAPHED WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

This well-known "Whirlpool" nebula was the first to show a spiral form in Lord Rosse's great telescope. He thought it could be resolved into stars, but although there are a great number of nebulous condensations, the star discs which actually appear on the photograph have no connection with the nebula.

interpreted as a movement of recession from the Solar System. Slipher, in America, has found such positive motions in the line of sight up to 1,800 km./sec., but the usual velocities found are between 400 and 600 km./sec., which, of course, are very greatly in excess of the line of sight velocities of stars, which rarely reach 100 km./sec. Not all the line of sight velocities of the spiral nebulæ are positive or away from the Solar System. A little group of four in the South Galactic Hemisphere around longitude 80° and latitude 22° are negative or approaching us. But this group includes the two spiral nebulæ of largest angular size in the whole sky, the Andromeda Nebula and M.33, which are also probably the nearest. It has been suggested that the large positive velocities are not real, but due to a displacement effect similar to that of the predicted Einstein displacement of the solar spectrum lines. The great variation found between the various spirals, which have been examined for line-of-sight displacements coupled with the fact that minus velocities do occur, seems definitely to dispose of this view. A much more probable solution is that advocated by H. N. Russell in America and Professor Lindemann in this country. Reference has already been made to the dark nebulæ and their origin as clouds of fine dust swept away from the neighbourhood of the high temperature stars. We may quite reasonably expect that such clouds would ultimately be expelled from the Milky Way altogether by the combined radiation of the stars. As the helium and hydrogen stars exert a radiation pressure on such minute particles, up to 100 times that of gravitational force, it is quite conceivable that velocities of 1,000 km./sec. and more would be attained by these clouds in a direction away from the centre of radiation pressure in the Galaxy. The distribution of the velocities so far found with regard to the Galactic Equator and its poles is, in fact, not inconsistent with such a hypothesis. When the clouds have attained some distance from

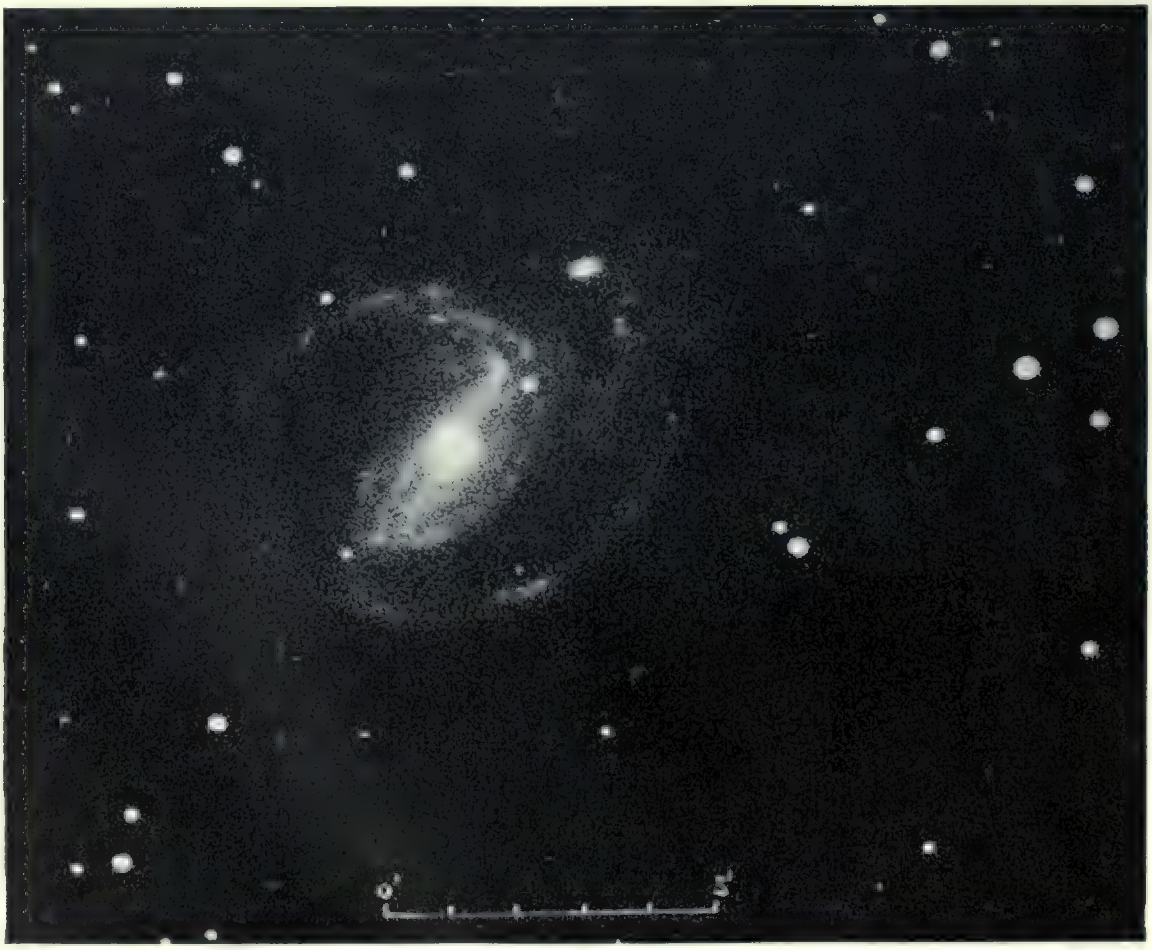
the plane of the Galaxy, concentration by mutual attraction would set up, involving a rise in temperature, so that ultimately the cloud would appear as a round compact nucleus shining by its own light. We have the exact counterpart of such hypothetical objects in the sky in the globular nebulæ. We may in any case take these globular nuclei as the primitive form from which the spiral arms evolve to form such a spiral nebula as the Andromeda Nebula, or the much more condensed spiral known as the "Whirlpool" in Canes Venatici. The theoretical side of the development of spiral arms from a central nucleus has been made the subject of an important work by Dr. J. H. Jeans in his "Problems of Cosmogony and Stellar Dynamics." Dr. Jeans first starts with a spherical nucleus, which under the influence of neighbouring bodies in space and of its own concentration commences a slow rotation. As the nucleus further condenses the speed of the rotation increases so that a flattening of the poles takes place, and it becomes an oblate spheroid. The still increasing speed of rotation finally produces a sharp-edged figure, known as lenticular or lens-shaped, in which the ratio of the equatorial and polar diameters is about three to one. This is the critical stage of the nebula, as such a formation is essentially unstable. A slight disturbance from outside sources is then sufficient to start a kind of tidal action, and two projections diametrically opposite to one another appear on the equator of the nebula ; ultimately nebulous matter is ejected into space at each of these projections,



THE SPIRAL NEBULA N.G.C.2835. PHOTOGRAPHED WITH THE THIRTY-INCH REFLECTOR OF THE HELWÂN OBSERVATORY.

An example of a four-branched spiral. There are several condensations in the outer regions of this nebula which bear out Dr. Jeans's theoretical work on the spirals.

and as the nucleus is always rotating, the matter assumes a spiral form known as an "equiangular spiral" under certain assumptions as to viscosity. This is a purely theoretical account of the formation of the spiral nebulæ, based on mathematics, but there is plenty of observational evidence that Dr. Jeans's theory is well founded. We should not expect to find many examples of the intermediate stages in the sky, as these stages are unstable and short-lived. Most of the nuclei destined to form spiral arms by rotation and tidal action would have already done so, and consequently by far the greatest number are either developed spirals or undeveloped nuclei. Another circumstance bearing on the probable occurrence of these intermediate stages is the law of random distribution of angles over the whole sky. It is evident that if the lenticular nebulæ were observed from our view point at right-angles to the plane of rotation, they would appear circular, and only those in which the planes lie in the line of sight would show their real form. The theoretical average angle to the line of sight over the whole sky is thirty degrees. We should on this account expect the lenticular form to be rarely visible as such. There are, however, some nebulæ which exhibit an undoubted lenticular outline: such are the two objects N.G.C.3115 and 5866, and the more developed example N.G.C.4594. A curious feature in the further development of the spirals and of some lenticular nebulæ as well, is the presence



THE SPIRAL NEBULA N.G.C.1097. PHOTOGRAPHED WITH THE THIRTY-INCH REFLECTOR OF THE HELWÂN OBSERVATORY.

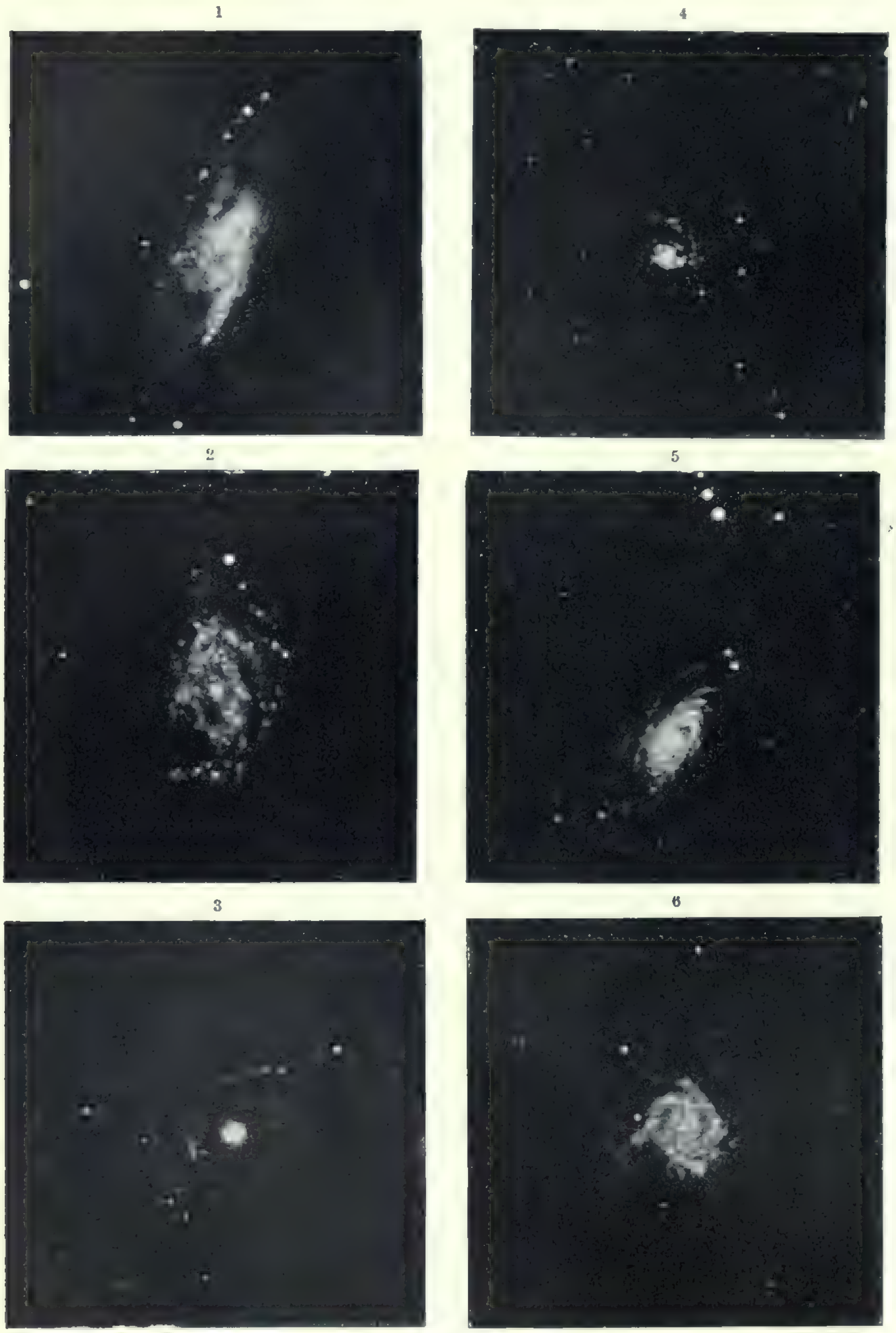
This is the largest example of the S-shaped spirals yet photographed. In these cases the spiral arms are not ejected from the nucleus, but from each end of a band of luminous material traversing the nucleus. This type is specially common in the southern sky. The nucleus with a short exposure shows an irregular disc something like a planetary nebula. An elongated nebula of the globular type is to be seen near the principal nebula.

[G. W. Ritchey.

THE "EDGE-ON" SPIRAL NEBULA H. V 24, N.G.C.4565. PHOTOGRAPHED WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

This is the largest "edge-on" spiral nebula in the North Galactic Hemisphere, and lies quite close to the pole. The oblate nucleus from which the spiral arms have evolved is very well shown. The nebula is somewhat condensed, but not sufficiently so to have taken up all the dark matter at its periphery, which forms a band of absorption.

of a dark line or band of absorbing matter along the periphery of the disc. It is very conspicuous in many of the spiral nebulæ which appear "edge-on," and must be interpreted as cool matter given off at the edge of the rotating lenticular disc. This absorbing band is always present in the spiral nebulæ which are uncondensed, but it gradually disappears as the condensed type is reached. This brings us to some further considerations as to the development of spirals. Those of the type of the spiral nebula M.64 show no condensations into brighter nodules, and the light curve, if plotted across the central region, would be an almost continuous curve from zero on each side to a high peak in the centre where the nucleus comes. But other spirals, such as the fine object M.81 in Ursa Major, while still possessing a very bright uncondensed nucleus, are broken up in the outer regions into separate bright condensations or nodules. This phenomenon is also discussed by Dr. Jeans: he says, "It can be shown that a long continuous jet of compressible matter issuing from a source could not remain of uniform line-density. A configuration of uniform density would be unstable, and the jet would tend to form condensations or nuclei around which the whole of the matter of the jets would aggregate." This process of condensation in the spiral arms appears considerably advanced in some of the spirals, and the matter which is perpetually leaving the nucleus and flowing along the



From "Knowledge"] [*J. J. Lee.*

SIX SPIRAL NEBULÆ IN THE NORTH GALACTIC HEMISPHERE. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

No. 1.—H. V 43, N.G.C.4258, in Ursa Major, is of large angular diameter and has some striking nebular condensations in the outer whorl of the spiral. No. 2.—H. II 730, N.G.C.3726, in Ursa Major, is a much condensed spiral with a bright stellar nucleus. No. 3.—M.100, N.G.C.4321, in Coma Berenices, is also an example of the much-condensed filamentous nebula, with a bright well-defined nucleus. No. 4.—M.99, N.G.C.4254, in Coma Berenices, is so condensed that the condensations have every appearance of star discs of about the sixteenth and seventeenth magnitudes. No. 5.—M.88, N.G.C.4501, in Coma Berenices, has a nucleus of the uncondensed type, incipient condensations appearing in the outer regions. No. 6.—M.61, N.G.C.4303, in Virgo, is a good example of the spiral nebula where the nucleus is almost stellar and quite small, most of the matter which was once in the nucleus having passed into the spiral arms.

arms naturally much weakens it, ultimately both in mass and in brightness. We thus have spirals consisting almost entirely of condensations with no very definite nucleus, as in N.G.C.253. A practical proof that the nuclear matter actually does flow from the nucleus along the spiral arms has been furnished by Van Maanen at the Mount Wilson Observatory. Two photographs of the spiral Nebula M.81 in Ursa Major exposed at an interval of eleven years with the five-foot reflector, were compared and measured, with the result that an outward motion along the spiral arms was detected. The amount of this motion was very minute in actual linear displacement on the photographic plate, but it was surprisingly large from the cosmical standpoint, for it meant that one turn of the spiral would be completed in 58,000 years. The diagram given on page 564 shows the kind of motion found, and the direction and magnitude of the mean annual motion. This

is by no means the only spiral nebula in which similar displacements have been measured, and there is no reason to doubt the accuracy of the measurements. In any case, another interval of twenty years will quite conclusively prove the existence or otherwise of these displacements. Another investigation on motion in spiral nebulæ undertaken at the same observatory by spectrographic means, was on relative movements in the oblate nucleus of the Andromeda Nebula. From our standpoint the nucleus appears roughly circular in outline, but the plane of the nebula is evidently inclined to the line of sight at an angle of about 15°, and we know from the "edge-on" spirals that the section of the nucleus is lenticular. Here a certain motion of rotation was found amounting to 58 km./sec. at points 2′ from the centre of the nucleus. The extraordinary feature as to this rotation was that the resulting measures, when plotted on a graph, were rectilinear, which must mean that the nucleus rotates as a solid body; one would have expected angular motion corresponding to the inverse square law from the centre of the nucleus, such as exists in the Solar System. Another curious feature which has been brought out by photography is the difference in colour between the nuclear and outer regions of the spirals. When an ordinary rapid plate, sensitive to the blue and ultra-violet end of the spectrum, but not to the green, is exposed on a spiral such as M.64, the result is different from a similar exposure on an isochromatic plate sensitive to the green and shielded from the blue end of the spectrum by a light yellow screen. In the latter case, the nucleus comes out strongly, but the spiral arms are comparatively much fainter, indicating that they are deficient in green light and the longer wave-lengths. It is necessary to be

THE SPIRAL NEBULA H. V 2 VIRGINIS, N.G.C.4536. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

An example of a partially developed spiral, in which the spiral arms have only completed half a complete turn. The nucleus is small and almost stellar in character. The small, much-elongated nebula below it, is a spiral seen edgewise.

careful in drawing conclusions from such differences in contrast shown by the two kinds of plate, as the contrast factor varies considerably between panchromatic and isochromatic plates dyed with various aniline dyes and the ordinary undyed plate, but the isochromatic plate certainly gives much more reliable results than the panchromatic, and the undyed plate gives comparable results in the blue region. Before fully accepting the reality of this unlooked-for effect, a more rigorous series of experimental photographs is perhaps necessary. It is, however, a point of great interest, for it suggests that some of the light of the spiral arms is not inherent, but reflected by minute particles of dust. This again is in accordance with the hypothesis already mentioned that the spirals consist of enormous concentrations of finely divided matter, probably expelled originally from the Milky Way by radiation pressure from the stars. The only obvious source of such reflected light is the bright nucleus itself. Owing to the natural disposition to make as fine a picture as possible from the negatives, photographic strengthening and manipulation has resulted in a totally erroneous conception of the comparative brightness of the nucleus and the spiral arms, the one in reality being usually several hundred times as bright as the other. We have already mentioned the occurrence of condensed nodules in the outer regions of certain spirals; the Andromeda Nebula, which we have described at some length, is the great example of the uncondensed type, while in M.81 the central portion at least is still uncondensed. We will now take another great spiral, second only to the Andromeda Nebula in apparent dimensions, and situated within a few degrees of it in the sky. This is the nebula

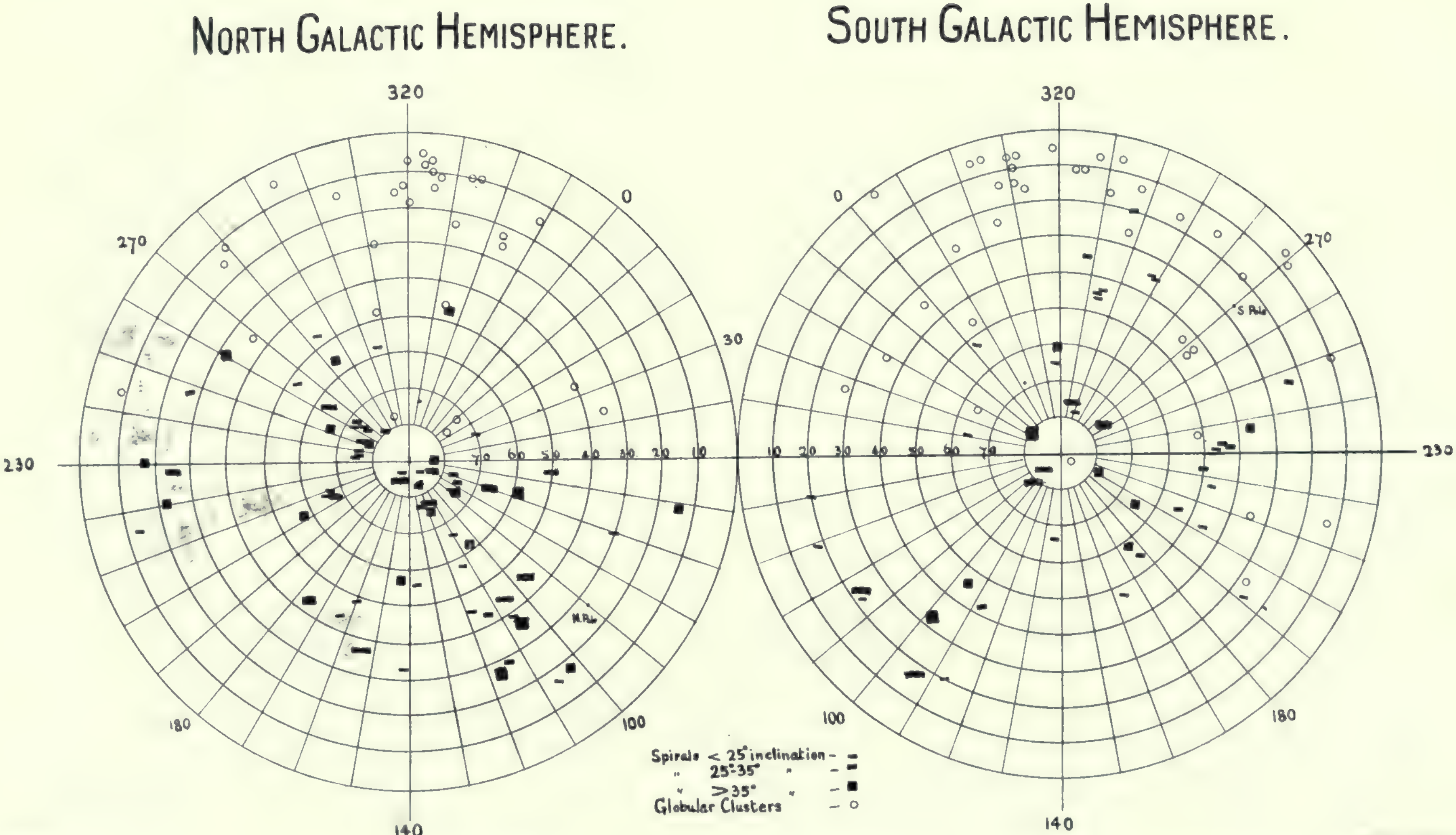
THE SPIRAL NEBULA H. V 44 CAMELOPARDI, N.G.C.2403. PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

An example of the same type as M.33, and the nearest to the Galaxy of the spirals of large angular diameter in the North Galactic Hemisphere. It is in a region where only large spirals are found.

From "Knowledge."] [*G. W. Ritchey.*

THE SPIRAL NEBULA M.33, N.G.C.598 IN TRIANGULUM. PHOTOGRAPHED WITH THE SIXTY-INCH REFLECTOR OF THE MOUNT WILSON OBSERVATORY.

With the exception of the Great Nebula in Andromeda, this is the largest in angular size in the sky, and it may actually be the largest if all



From] [M.N., R.A.S.

DIAGRAM SHOWING THE GALACTIC DISTRIBUTION OF THE GLOBULAR STAR CLUSTERS AND THE SPIRAL NEBULÆ OF FIVE MINUTES DIAMETER AND UPWARDS.

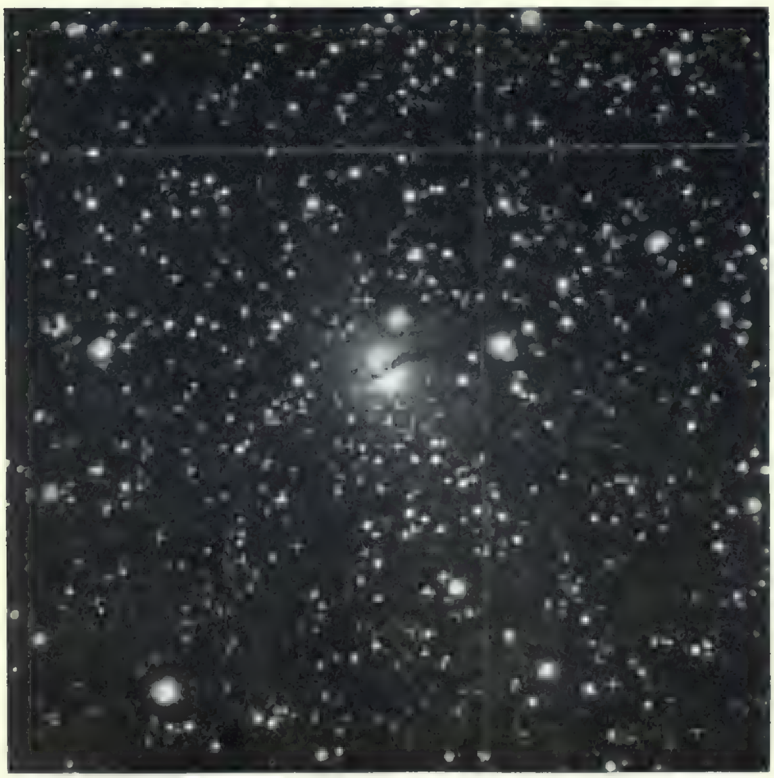
In this diagram the sky is treated as if it were two flat discs, the edge of each disc representing the galactic equator and the centre representing the pole. The figures round the circumference give the galactic longitudes, and those from the edge to the centre the galactic latitudes. The small circles indicate globular star clusters, and the black squares and rectangles the spiral nebulæ, the larger size representing spirals of ten minutes diameter and over, and the smaller size those of five to ten minutes diameter. It will be seen that the distribution of each class of object is distinctive, and only in a few regions is there any intermingling.

known as M.33 or N.G.C.598, illustrated on page 579. It can be seen at a glance that here we are dealing with a totally different type of spiral. Everywhere except in the actual nucleus, condensations and granular nodules of irregular shape are present while the nucleus itself is only a faint object, very inconspicuous to the eye in a large telescope. Until the nebula was photographed, the great extent and intricate detail of this object was quite unknown. Its great angular diameter would give it a position with the Andromeda Nebula as one of the nearest spirals to the Solar System : it is especially remarkable that M.33 should, like its giant neighbour, have a considerable motion of approach towards us. This motion was obtained spectrographically as in the other cases, but as the nucleus of the nebula was too faint to make any impression on the photographic plate of a spectrograph, a small rather bright nebula in the outer regions giving a bright line gaseous spectrum was photographed at the Lick Observatory. Many small faint nebulæ lie in the surrounding regions of the sky, and Professor Max Wolf, who has made a special study of these, considers that they form extensions of the spiral arms of the principal nebula. If this is so, and it is in all probability correct, then we must assign to M.33 as great an angular size as the Andromeda Nebula itself. All the stages of condensation in a spiral nebula are very well shown here. There is the curious granular appearance, which has been compared to frogspawn, which tends ultimately to form groups more or less equally spaced. These groups, and not the granulations, are the drop-like condensations postulated by Dr. Jeans's theory, by the apparent spacing of which he calculates the distance of various spirals. It may, however, be remarked in passing that by taking the granulations in the extreme outer regions of the Andromeda Nebula instead of the groups, Dr. Jeans has placed the nebula at a distance which is not warranted by the general scale. A great many minute points of light, having the appearance of star discs on the photograph, appear in all parts of M.33, while over all lies a faint cloudy mass of nebulosity without structure, evidently matter still uncondensed. We must certainly regard the granulations as self-luminous, as there is no question here of the nucleus being brilliant enough to illumine distant regions. These two great

THE SPIRAL NEBULA M.63, CANUM VENATICORUM, N.G.C.5055 PHOTOGRAPHED WITH THE THIRTY-SIX-INCH REFLECTOR OF THE LICK OBSERVATORY.

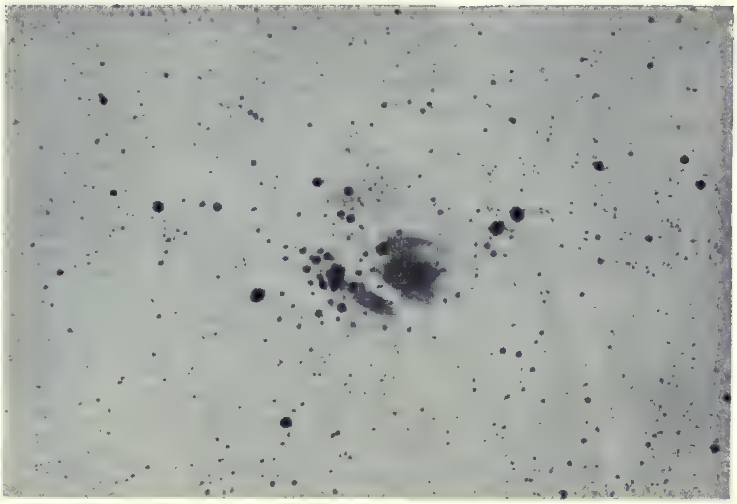
The details of the nuclear regions are lost in the illustration owing to over-exposure, but it can readily be seen that the nebula does not follow the normal form of spiral development. It is a multi-spiral, with many condensations in the outer portions.

spirals, the largest in angular size in the sky, are both in the South Galactic Hemisphere. Another large spiral, seen edge-on by us in the same neighbourhood, is N.G.C.891, illustrated on page 566. The dark band of absorbing matter at the periphery of the nebula is very striking. Four other large spirals form a group near the South Galactic Pole, one of which, N.G.C.253, has already been mentioned. The others are N.G.C 55, 247, and 300, all having been photographed first with a reflector at Helwân Observatory. These, with the exception of N.G.C.891, are the five largest spirals in the sky. The number of spirals in the southern hemisphere is not nearly so great as in the northern, and they are much more widely spread. This and the very large angular diameters of the five referred to, are evidence that the division of the spiral nebulæ by the galactic plane is by no means an equal one. The two diagrams on page 580, in which the positions of spirals down to 5′ diameter are plotted, give a good idea of their relative distribution. In the northern hemisphere, the largest spirals are in the region of Ursa Major and Canes Venatici, where they appear with little concentration over a wide area. These include the fine spiral M.81 (*see* page 563), the well-known "Whirlpool" nebula in Canes Venatici, the condensed spiral M.101, illustrated in the Introduction, and several other large spirals, most of which appear in the illustrations. Near the North Galactic Pole lies the largest of the edge-on spirals N.G.C.4565, which shows a conspicuous band of absorbing matter in the outer parts. On each side of the Galactic Pole, about longitudes 80° and 270°, some hundreds of spirals of medium and small size are massed together. The region of the Galactic Pole itself is comparatively free from spirals, but it is remarkable for a vast number of small featureless nebulæ, which can only be discriminated from stars by their hazy outlines. The nature of these is uncertain: they resemble the condensations appearing in the spirals more than anything else, and there is no reason for thinking they are very distant spirals. Beyond the North Galactic Pole from our latitudes another region of spiral concentration appears in Virgo. Here the nebulæ are on the average of smaller angular diameters, so the general plan seems to be a wide band of these objects, starting in Ursa Major with those of large angular diameter, and increasing in number, but decreasing in average size, as we pass beyond the Pole. A very remarkable fact is the absence of spirals in the semi-hemisphere of the sky which contains the constellations Hercules, Corona Borealis, Serpens and other well-known northern constellations, as well as the southern constellations, Pegasus, Libra, and Aquarius. Whatever the explanation may be, it is at least significant that this particular semi-hemisphere contains more than half of the globular clusters in the entire sky.



ENLARGED CENTRAL PORTION OF THE FRANKLIN ADAMS CHART CONTAINING THE NEBULA N.G.C.5128.

This is the same nebula which is reproduced from the Helwân series on page 571. The difference in the size of the star images in the two photographs as well as the difference in scale is well shown.



A NEGATIVE IMAGE OF THE NEBULA AND CLUSTER M.8, PHOTOGRAPHED WITH THE BRUCE TELESCOPE AT AREQUIPA, PERU. This photograph gives a clearer idea of the bright stars involved in the nebula than the long exposure photograph reproduced on page 526.

Not all the spirals are of the form known as the equiangular spiral. It is quite a usual thing for one or more of the spiral arms to be divided into two branches, as in N.G.C.2835. In others there is a broad band of nebulosity each side of the nucleus from the ends of which short spiral arms start, forming the letter S. An example of this is N.G.C.1097. In others an oval ring only appears with no trace of spirality at all. As Dr. Jeans suggests, such rings may have been thrown off by the rotating lenticular nuclei in the absence of any disturbing factor to induce the tidal effect responsible for the ordinary spiral form. Sometimes, again, spiral development in more than one plane is shown as in N.G.C.151. The character of the spiral arms also varies very much from one example to another. In some cases they are broad and mottled over with condensations, in others they are mere filaments with no condensations. The nuclei also range from luminous spheroids with great central brilliance to minute discs only to be distinguished from star discs by their hazy outline under magnification. There is, in fact, a great variety of individual examples, with conformation to the general type, as is everywhere found in nature.

THE MAGELLANIC CLOUDS.

We have still to mention two very curious formations in the southern sky, both quite out of reach in northerly latitudes—the Magellanic Clouds, or, as they are usually termed, the Nubecula Major and the Nubecula Minor. These will be also considered in another chapter of this work, but as they are rich in nebulæ and clusters, they cannot very well be omitted here. It has, indeed, been suggested that they are actually spiral nebulæ closer to us than any other spirals, but their general shape is far removed from that of a typical spiral. They seem rather to show galactic affinities, as the nebulæ they contain are of the gaseous variety, both irregular and planetary. This indicates the existence of high temperatures, which is also proved by the presence of a large number of stars of the Wolf-Rayet or " O " type of spectrum, some as bright as the ninth magnitude. A feature which places these objects outside the Galactic System is their large velocities of recession of 248 and 168 km./sec. respectively, velocities which are comparable with those of the spiral nebulæ rather than the galactic stars. Professor Hertzsprung, who has made a special study of these formations, places them at the enormous distance of 40,000 light-years. Such an estimate seems altogether too high for stars and nebulæ comparable in brightness and size with similar objects in the Milky Way. But the whole question of the real dimensions of the Galaxy, and of the distances of the spiral nebulæ, is at the present time in a state of flux, and there is no general agreement. A view which is strongly held in some quarters is that the Galactic System is itself a spiral nebula, no greater in dimensions than such nebulæ as the Andromeda Nebula. The other view regards the Milky Way as the great structural feature of the visible universe to which the globular star clusters and the nebulæ are subsidiary. The fact that the globular clusters are in general approaching the plane of the Galaxy and the spiral nebulæ receding from it in some cases with enormous velocities, seems to the writer to favour the latter view, especially if it be conceded that the spirals may have originated in clouds of finely divided matter.

All the evidence which has been accumulating during recent years is in favour of placing the spiral nebulæ in a class by themselves, for which we have no analogies either in the Solar System or the Milky Way. One fact which must have great significance is the apparent antipathy of spiral nebulæ to globular clusters. If both are plotted on a diagram together, it will be quite evident that only in rare cases are they found in the same region of the sky, and even in such cases they are only the stragglers or "erratics" that mingle. We have already pointed out that the star clusters are mostly concentrated in one hemisphere of the sky and the large spirals in the other. If we take the pole of the star cluster hemisphere in Sagittarius as representing the direction of the centre of the Galaxy, then we must imagine that the star clusters lie near the central part of our universe, being concentrated on each side of the great star masses which form the centre of the Galaxy itself. Radiating away from these central regions in all directions lie the spiral nebulæ; those at the greatest distance from the galactic plane and of the smallest apparent size, stretching well into the star cluster hemisphere; those of the largest apparent diameter and comparatively close to the galactic plane lying behind us, if we imagine ourselves looking towards the apex in Sagittarius. This seems the most probable explanation of the known distribution of the globular clusters and the spiral nebulæ.

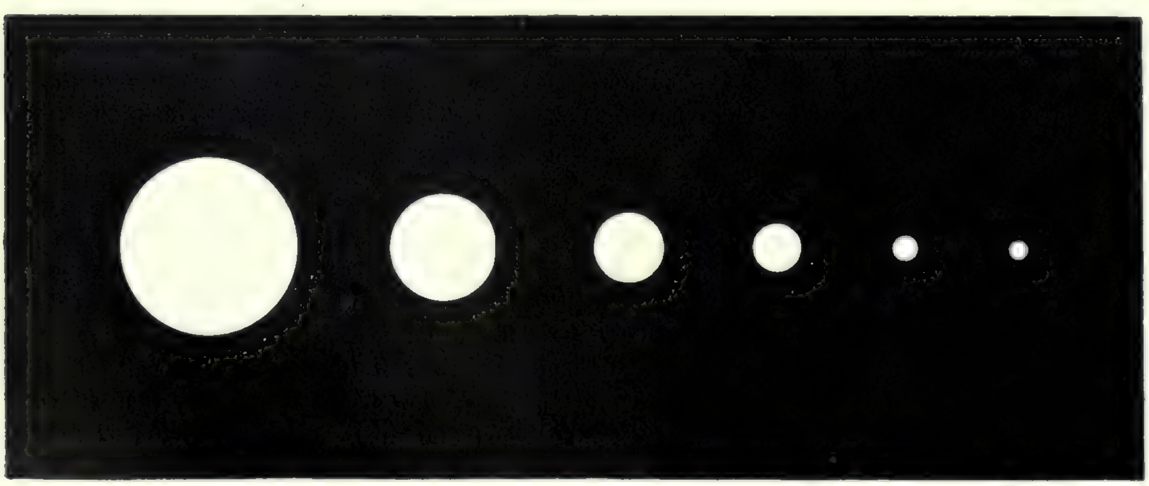
CHAPTER XV.

VARIABLE AND "NEW" STARS.

By Dr. W. H. Steavenson, F.R.A.S.

In the early chapters of this Work the reader was introduced to bodies which are, comparatively speaking, near neighbours of the Earth, and it was therefore possible to put before him many detailed illustrations of their actual surfaces. Unhappily, this cannot be done in the case of the stars, whose vast distances from us reduce them to mere points, even in the most powerful telescopes. We are thus limited, so far as direct observation is concerned, to a study of (1) their positions and motions, real and apparent, and (2) their light. It is with the latter that we shall be dealing in the present chapter.

The study of starlight, like chemical analysis, may be either qualitative or quantitative, according as we are concerned respectively with its nature or amount. The first of these two has already been dealt with in Chapter XII, and we shall here direct our attention mainly to the second.



[W. H. Steavenson.

STELLAR MAGNITUDES.

Stars are divided, according to their apparent brightness, into a series of classes termed "magnitudes." The relation between these classes has remained substantially the same since the system was introduced by Hipparchus, but the light-ratio is now more rigidly defined, and is such that any star appears 2·512 times as bright as one a magnitude fainter in the scale. A range of six magnitudes is represented by the relative areas of the above discs.

The fact that the stars differ greatly in brightness from one another is so obvious that it must have forced itself on the very first man who ever gazed at the Heavens, and repeated observations must further have shown him that, in general, no obvious change in the relative brightness of the stars occurred from night to night, or even from year to year. Thus arose among the Ancients the general impression that the Heavens (apart from Sun, Moon, and planets) were typical of all that was unchanging and unchangeable. As a consequence of this impression, no great importance was attached in early times to the exact estimation and record of the amount of each star's light, and, when any attempts were made in this direction, as by Hipparchus and Ptolemy, it was chiefly for purposes of ready identification. It is only in comparatively recent times that closer observation has revealed the fact that, while most of the bright stars are sensibly constant in light, certain of them exhibit decided changes from time to time. But, even up to a hundred years ago, such variability was still regarded as rather exceptional, and few examples were known. To-day, however, the number of stars (mostly telescopic) known to vary in their light is to be reckoned in thousands, and we have come to regard variability as a phenomenon that is anything but exceptional in the Heavens.

It will readily be understood that the discovery of stellar variability, coupled perhaps with the occasional appearance of "New" or "Temporary" stars, gave a fresh importance to the exact determination, not only of the positions, but also of the brightness of the stars in general, with a view to the more ready detection of change. Thus the quantitative measurement of starlight owes its origin and development very largely to the existence of "variables," and it therefore seems appropriate that a brief review of the history of stellar "photometry," as it is called, should be given at this point.

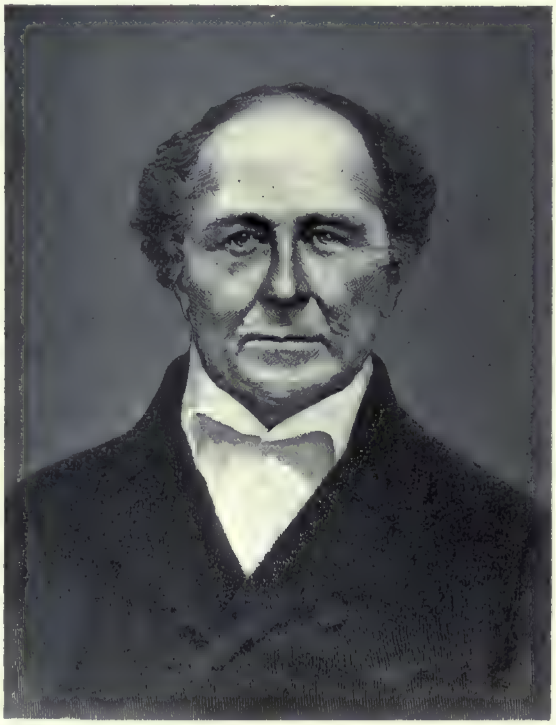


Photo by] [*Augustin Rischgitz.*

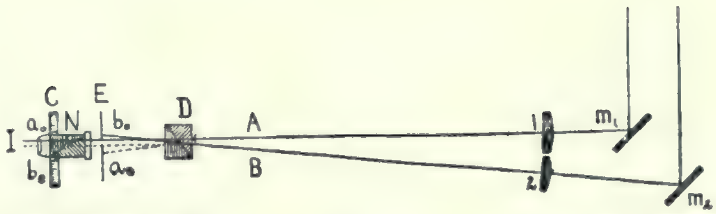
F. W. A. ARGELANDER.

Argelander's introduction of the decimal division of star magnitudes in the middle of last century marked the beginning of accurate stellar photometry. He discovered and observed at Bonn a large number of variable stars and originated a method of comparison still in use by those who study these objects. His great catalogue, The *Bonner Durchmusterung*, contains the positions and magnitudes of 324,198 stars observed by him and his assistants down to a distance of ninety-two degrees from the North Pole.

The first systematic attempt to classify the stars according to their brightness was made by Hipparchus in 127 B.C., and, though his original work is lost, his results have been handed down to us by Ptolemy. Hipparchus divided the stars, quite arbitrarily, into six classes, this number being considered just about sufficient to give a fair idea of the brightness of any star for purposes of identification. (In much the same way we divide boots and other articles into "sizes.") These six rough divisions Hipparchus termed "magnitudes," but it must be clearly understood that no reference to the *actual* sizes of the stars is implied by this word, which simply denotes the effect produced on the eye by different degrees of brightness. The brightest stars were classed as of the "First" magnitude, and the faintest visible of the "Sixth." Now, Ptolemy noted that the human eye could readily detect at least two intermediate grades between any two of the broad divisions of Hipparchus, so that, for instance, he recognises, between the fourth and fifth magnitudes, stars that may be called "faint fourth" or "bright fifth" without being *exactly* of either magnitude. Similarly, referring again to boots, we speak of "small twos" or "large eights."

This virtual division to thirds of a magnitude provides for about the smallest differences of brightness

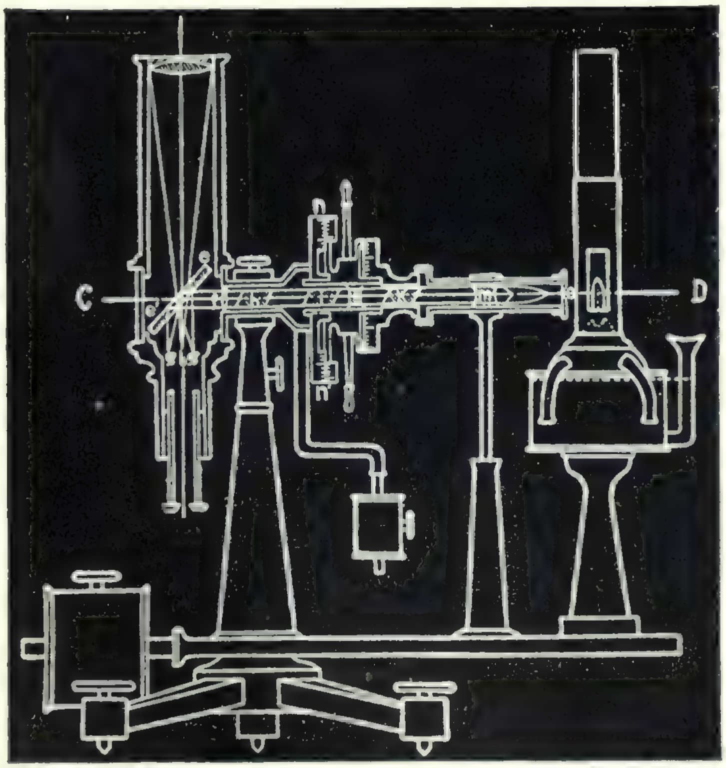
that the untrained eye is readily able to detect, and it so far answered the requirements of the earlier observers that it was retained without material alteration right up to the Nineteenth Century. It was not until about 1850 that the practised observer Argelander introduced subdivisions as small as one-tenth of a magnitude. Meanwhile, in the earlier part of the century, various other observers (notably J. Herschel, Steinheil, Struve, and Johnson) had been revising for themselves the magnitudes assigned by Ptolemy, without, however, disturbing the broad outlines of the classification into six degrees of brightness. The general plan was to adopt as correct certain of Ptolemy's stars of each magnitude, and, taking these as "standards," to adjust the estimates for the remainder to conform with them as closely as possible. Naturally, personal differences between the various observers, coupled with the adoption of different stars as "standards," resulted in some disagreement between the magnitudes finally arrived at. But the determinations agreed sufficiently well to yield a very important result, pointed out by Johnson in 1851. This was the establishment of the fact that, adopting Ptolemy's division into six magnitudes, each observer found practically the same difference between any two magnitudes all down the scale. This difference amounted to an increase of very nearly two and a half times in the light of the stars as one passed up from one magnitude to the next. Some time before this Sir John Herschel had estimated that a star of the first magnitude gave about 100 times as much light as one of the sixth, and this estimate was found to agree quite closely with the average results of observers as examined by Johnson. In this way the true physical ratio existing between Ptolemy's several magnitudes was for the first time satisfactorily revealed, and it appeared desirable, for the sake of future



From "Variable Stars."] [*By C. Furness.*

THE HARVARD MERIDIAN PHOTOMETER.

With this instrument the light of the stars is compared direct with that of Polaris, which is used as the standard in determining stellar magnitudes. Two similar object-glasses (1 and 2) are so arranged as to form their images side by side at E. The two mirrors (m_1 and m_2) are so arranged as to point to the star and Polaris respectively. D and N are parts of a polarising apparatus by rotation of which the two stars can be made equal in brightness. The amount of rotation required to produce this equality is read on the circle C, and from this the difference in magnitude is easily deduced.



From "Variable Stars."] [*By C. Furness.*

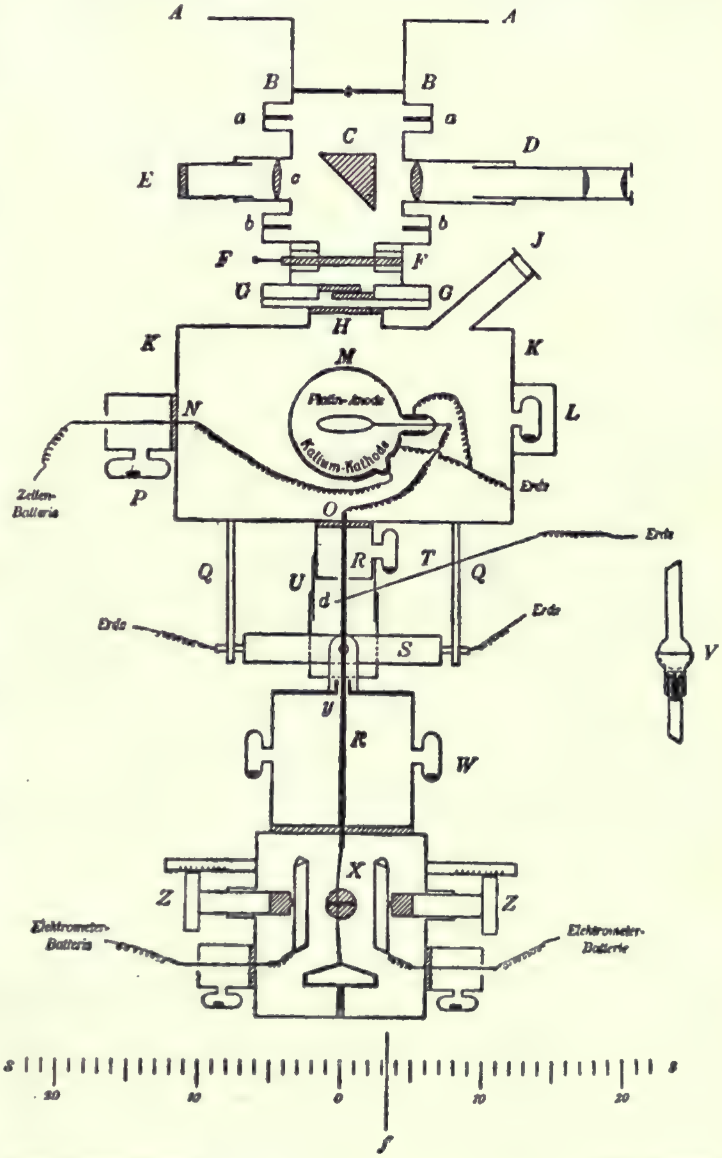
THE ZÖLLNER PHOTOMETER.

By means of this instrument an artificial standard of light is compared with the stars whose brightness is to be measured. The observing telescope is seen on the left. In it is inserted an unsilvered glass mirror, which reflects towards the eye the light of the oil lamp on the right. The light passes through a pin-hole, thus forming an artificial "star" in the same field as the real one. By a polarising apparatus the former can be adjusted to equality with the latter, and the amount of rotation of the polariser gives a measure of the difference between the two.

observers, that a fixed value for this ratio should be universally adopted. The value finally decided upon, on the suggestion of Pogson, was 2·512 to 1, and this has ever since been used as a basis for all calculations relating to stellar magnitudes. The particular value here mentioned was adopted because its logarithm, used very frequently in computations, is exactly 0·4, which simplifies matters considerably.

One more step was required in order to ensure uniformity in the determination of stellar magnitudes; this was the adoption of one definite standard, on which all measures, by whomsoever made, should ultimately depend. Eventually Polaris, on account of its ready accessibility at all times and from most places, was adopted by universal consent, and it was agreed that its magnitude should be regarded as being exactly 2·1. All that is now required in order to determine the magnitude of any star is to find what ratio its light bears to that of the Pole Star, from which its difference in terms of magnitude can readily be found by applying Pogson's constant of 2·512. It is interesting to notice in passing that the adoption of this ratio gives a first magnitude star just a hundred times the light of one of the sixth, which is in exact agreement with Sir John Herschel's estimate.

It is to be noted that this modern readjustment and standardisation of stellar magnitudes is ultimately based on the main outlines of the rough classification of Hipparchus, of which it is in reality the fulfilment. Such differences as are produced are comparatively small, especially in the case of the fainter naked-eye stars. One curious result, however, of the readjustment has been the creation of *negative* values for certain abnormally bright stars. Thus (assuming Polaris $= 2^{\mathrm{m}}{\cdot}1$) we find that Aldebaran is of magnitude 1·1; but Capella is brighter still, and must therefore be represented by a number (actually 0·21) that is less than unity; while for two stars, Canopus and Sirius, the magnitudes are so much above the normal that they have to be set down as *minus* quantities in the forms $-0^{\mathrm{m}}{\cdot}86$ and $-1^{\mathrm{m}}{\cdot}58$ respectively.



From "Variable Stars."] [*By C. Furness.*

A PHOTO-ELECTRIC PHOTOMETER.

This instrument is attached to the small end of a large telescope at AA. The light of the star whose brightness is to be measured falls through and on to the lower side of the glass bulb M. This lower surface is coated on the inside with potassium (Kalium), which reacts electrically to the light-stimulus. The reaction, which is proportional to the intensity of the light, is recorded by the movement of the thread of a delicate electrometer (X). At the bottom is an enlarged view of the scale along which the thread *f* is seen to move.

We must now proceed to a brief description of the principal methods whereby star magnitudes are determined.

The early observers, such as Hipparchus and Ptolemy, contented themselves with simple eye-estimates. These were sufficient where great accuracy was not aimed at, though there were naturally differences of personal origin between the results of various workers. It was not until the Nineteenth Century that any serious attempts were made to *measure* magnitudes accurately by instrumental means. The methods then introduced were founded on two principles, known respectively as those of *extinction* and *equalisation.*

In the case of the first of these the star whose light is to be measured is brought into the field of view of a telescope and its light is steadily reduced by artificial means (by contracting the aperture of the telescope or by the gradual insertion of a wedge of tinted glass) until it just disappears. The same performance is then repeated on some "standard" star, whose magnitude is assumed to be correct, and the difference between the brightness of the two stars is then readily found by comparison between the degrees of "dimming" required in each case.

The second method, that of equalisation, is applicable only where both stars are visible in the same field of view simultaneously. It consists in reducing the light of the brighter of the two (either by a wedge or polarising apparatus) until they both appear exactly equal. The amount of reduction required then gives the difference of brightness, as before. Often an "artificial" star, produced by optical means in the field of the telescope, is used, but the principle is still the same.

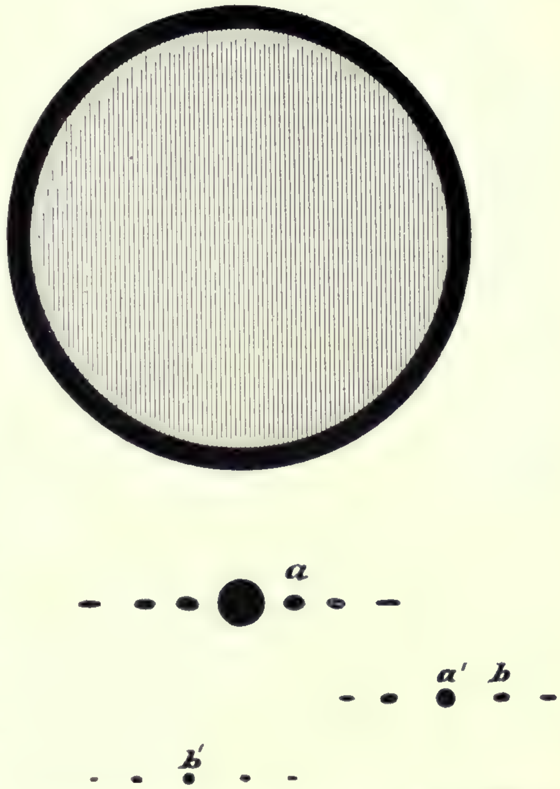
DETERMINATION OF MAGNITUDES BY PHOTOGRAPHY.

Stars of all degrees of brightness are reduced by their great distances to mere points of light, but their images on a photographic plate are enlarged by "irradiation" into discs. These vary in size according to the brightness of the star, and a simple measurement of their diameters gives the data necessary for calculating the relative "magnitudes," or apparent luminosities.

Both of these methods (especially the second) have been used with considerable success by different workers. The advantage of the extinction method is that it does away with the necessity of having the comparison star, real or artificial, in the same field, each determination being made independently. But many observers find it difficult to determine the exact point at which a star ceases to be visible. No two observers would agree as to this, and even the same observer will find variations in the sensitiveness of his eye (as well as in the state of the atmosphere) from minute to minute. On the other hand, the equalisation method demands the inclusion of the standard star in the same field, failing which an artificial star must be resorted to, and it is found difficult

to keep the latter constant in brightness and to make it look really like the object with which it is to be compared. The principal advantage of the method lies in the simultaneity of the comparison, which eliminates the effect of changes in the eye, and (in the case of a real comparison star) in the atmosphere, both objects being at the same altitude in the sky. Moreover, observers generally find it much easier to judge of equality than of disappearance.

Probably the most generally satisfactory visual photometer so far devised is that designed by E. C. Pickering, late Director of the Harvard College Observatory, U.S.A., and known as the "Harvard Meridian Photometer." This instrument consists of two telescopes, each of about four inches aperture, fixed side by side horizontally in an east-to-west direction. In front of each object-glass is a plane mirror, set at an angle of forty-five degrees, capable of rotation about the optical axis of the lens. It can thus be set to throw down the telescope the light of any star that is on or near the meridian. The two object-glasses are so tilted that both form their images sufficiently close together to be examined by the same eye-piece. The method of employing the photometer is to adjust the mirror of one telescope so as to direct the light of the Pole Star down the tube. The other mirror is then set to bring the star to be studied into the same field of view, both objects being now seen side by side. By a system of "polarising" prisms, placed between eye-piece and object-glass, the relative brightness of the two stars can now be so modified as to make them appear equal. The amount of rotation of the polariser necessary for this can be read off on a graduated scale and the relative brightness of the two stars can then be readily calculated. Thus each star is compared direct with the "standard," which saves much time and obviates errors likely to occur by intermediate comparisons. In addition to Polaris, several other stars near the Pole are often used as standards. These stars have been measured with special care and form what is known as the "Harvard North Polar Sequence." The observations are quickly made and require but little reduction. The most important correction required is that necessitated by the difference in altitude between the star and the standard. The increasing thickness of the atmosphere as one passes from zenith to horizon has a very marked effect on the brightness of the stars, and due allowance has to be made for this.

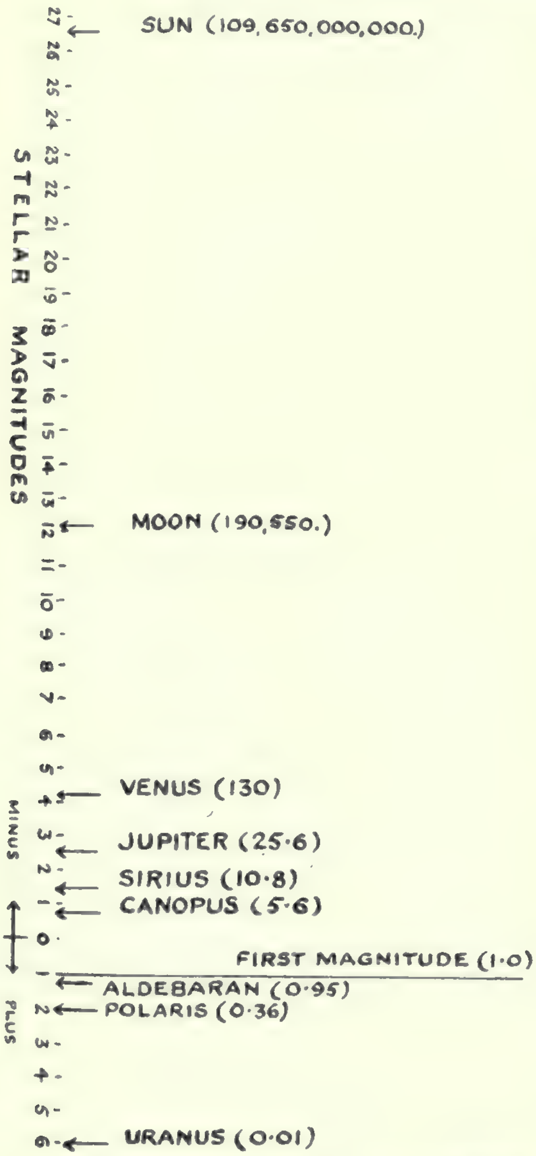


[*W. H. Steavenson.*

COMPARISON OF MAGNITUDES BY A GRATING. If a frame, crossed by a number of parallel wires, is placed in front of the object-glass of a photographic telescope, the result will be the formation of a number of small diffraction spectra on either side of each star image, as seen below. Those nearest the central image are nearly circular and can be compared with other stars on the plate. Since they bear a known and constant relation to the principal image, an extended set of standards of comparison is thus formed from the few original stars available. This serves to bridge the gaps which would otherwise occur, and makes possible the mutual comparison of stars of very unequal brightness, as shown above.

Many thousands of the brighter stars have had their magnitudes determined with this instrument at Harvard. The probable error of the published values is in general only a few hundredths of a magnitude, which is a great advance on most of the work of the earlier observers. Still, it must be borne in mind that each estimate depends ultimately upon the visual judgment of the observer in deciding as to the luminous equality of two points of light. In forming such a judgment there are many sources of error, of a personal nature, connected with the colour, relative position, etc., of the

two stars to be compared, and it is found impossible completely to eliminate or allow for these. For most purposes, however, accuracy to the nearest tenth of a magnitude is quite sufficient, though in special cases, as we shall see later, a still greater degree of precision is required.



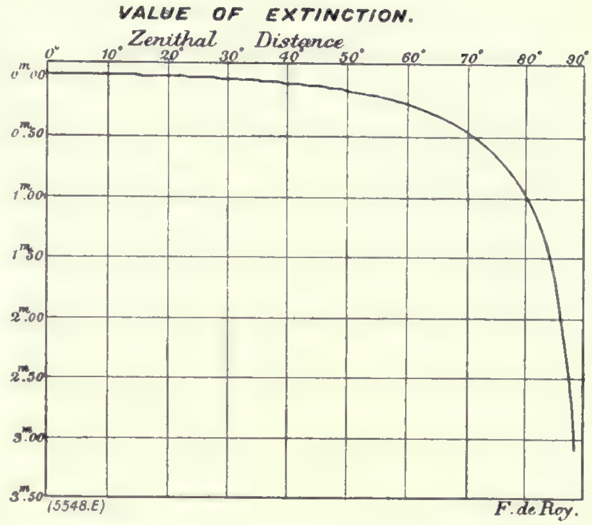
[*W. H. Steavenson.*

MAGNITUDES OF VARIOUS CELESTIAL OBJECTS.
The range of magnitudes here represented covers all the objects visible to the naked eye. A few typical examples are given here and there, and the figures in brackets beside them denote the ratio which their light bears to that of a first-magnitude star. Magnitudes below the sixth are only made visible by means of telescopes. Stars as faint as magnitude twenty-one have been photographed by large instruments.

In Chapter I brief reference was made to the practice of determining star magnitudes by means of photography. This method has proved of great value, especially in the case of the fainter stars and in statistical studies of stellar distribution. A glance at a photograph of any part of the Heavens will reveal the obvious fact that the images upon it are of very different sizes. Bond pointed this out in 1858, in the very early days of stellar photography, and suggested that accurate determinations of magnitude could be made by simple measurement of the diameters of the stars' images on the plate. Since then the method has come into general use and has given excellent results, though its practical application is beset by many pitfalls and is not quite so simple as Bond supposed. In fact experience has shown that photographic, like visual, photometry, has its own peculiar advantages and defects. The chief advantages are the partial elimination of the personal element by the substitution of an automatic registration of brightness, and the saving of time effected by the simultaneous recording of very large numbers of stars. Among the defects we must reckon anomalies in the character and relative intensity of the photographic images due to such factors as type of lens, brand of plate, time of development, and *colour* of the stars. Leaving the last of these for the moment, it may be said that each worker has to determine carefully for himself the exact effect of these factors before he can begin to make accurate measures of magnitude. He has, in fact, to construct a special formula, containing certain "constants," and with its aid he can then derive his results from a simple measurement of the diameters of the star images. An alternative method, less commonly used, is to photograph the stars out-of-focus, so that all form large discs of similar size. The magnitudes are then estimated by comparing the density or duskiness of the discs with a graduated strip of film whose density at any point is known. It sometimes happens that a plate contains so few stars, and of such widely different brightness that direct comparison between them is difficult. Two methods can then be employed to bridge the gaps in brightness. One is to give several exposures of different duration, moving the plate between each. The result is a string of images for each star, all differing in brightness by a known amount, so that the standards of comparison are made

to cover a much wider range of magnitude, supplying the lack of real stars of intermediate brightness. The second method has been very successfully used at Greenwich, and consists in placing before the object-glass a "grill" of parallel wires, arranged like the strings of a harp or piano. The effect of this grill is to produce by diffraction a diminishing series of fainter images (really small spectra) on each side of the principal star image. The difference in brightness between the several images is a constant quantity, readily calculable on optical grounds, and the range of magnitudes available for comparison is greatly increased, as in the first method described.

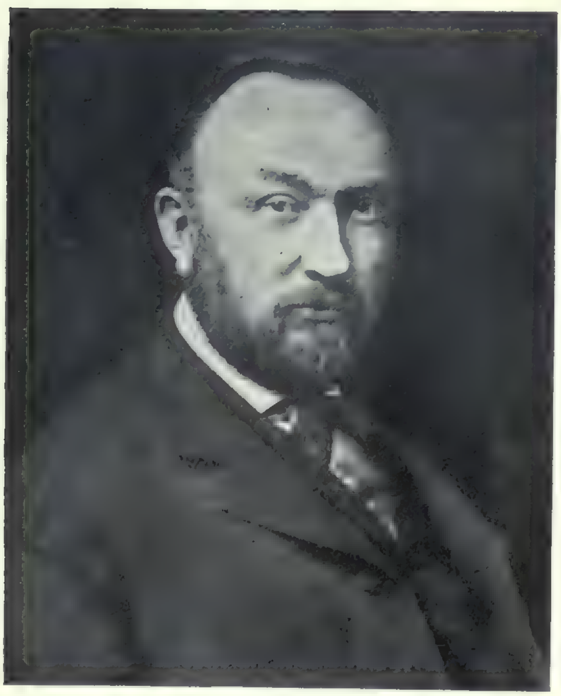
It should be noted that *all* photometric methods, photographic and visual alike, are relative in their application. That is to say all results are obtained by reference to some adopted standard or standards of magnitude. An individual observation of a star will not by itself



[Journal of B.A.A.

ATMOSPHERIC DIMMING OF STARLIGHT.

This curve shows the effect of altitude on the apparent magnitudes of stars. The nearer a body is to the horizon the greater is the thickness of the air through which we observe it. It will be seen that when a star is 80° from the zenith (that is 10° above the horizon) it appears a whole magnitude fainter than when overhead. At an altitude of 4° the difference is twice as great, or two magnitudes. Allowance has to be made for this effect when measuring the brightness of stars.



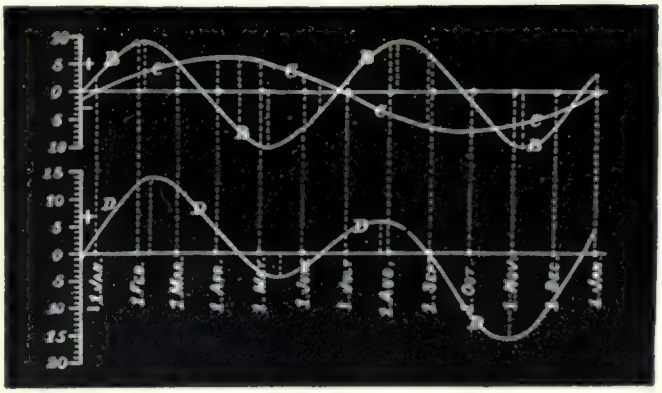
THE LATE PROFESSOR E. C. PICKERING.

Stellar photometry owes more to Pickering than, perhaps, to any other individual astronomer. Under his direction, at Harvard College Observatory, the magnitudes of many thousands of the brighter stars have been determined with great accuracy. Most of this work was done with the "meridian" photometer which he himself devised. He also did much to organise and extend systematic work on Variable Stars.

give a reliable value, since so much depends on the atmospheric and other variable conditions under which the work is done. It is therefore essential that in each case a "control" observation, as nearly simultaneous as possible, should be made of some standard star. Thus, in photographic photometry, it is a common practice to make one or more exposures on the field of the North Celestial Pole (where the stars have all been accurately measured) within a few minutes of the taking of the field under examination, and allowing all the images to fall on the same plate. In this way both the stars to be measured and the standards of comparison are photographed under nearly identical conditions and can be directly compared.

The scale and light-ratio adopted in photographic determinations of magnitude are the same as those used in visual work, and an even higher degree of accuracy is attainable. Yet the results obtained by the two methods are very far from being the same for all stars. The principal cause of divergence is difference of *colour*, and this is really the outstanding objection to the photographic method. If all the stars were white, or at any rate of the same colour, there would be little or no difference between visual and photographic

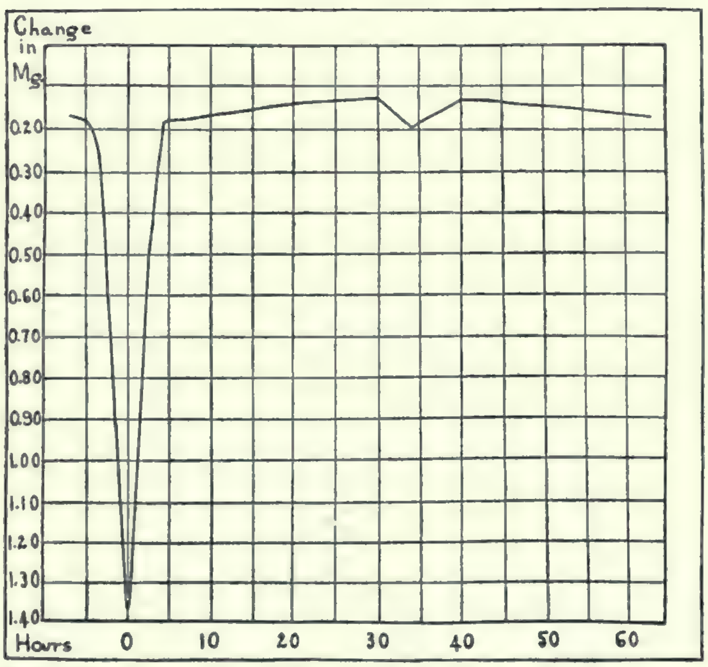
measures, but the ordinary plate is so much less sensitive than the eye to yellow and red light that stars of these colours form relatively feeble images, and therefore have too low a magnitude assigned to them. Until quite recently this constituted a great difficulty, since it introduced a rigid distinction between two systems which both aimed at the same results. There was, moreover, no question of adopting the one as correct and abandoning the other as fallacious. *Both* are "right" and each is consistent with itself. The trouble comes when we try to compare the two, and we then find that the eye and plate "see" so differently as to make the comparison almost worthless. Accordingly there have arisen two separate scales of magnitude, "visual" and "photographic," each excellent in itself but practically incomparable with the other. It will be understood that this is often a source of great inconvenience. It is particularly so when we wish to compare modern photographic observations with old visual estimates of some variable star, for we can never be sure how far apparent discrepancies between the two are due to actual change, and how far to mere difference of method.



ANALYSIS OF A COMPOUND CURVE.

The apparent irregularity of the lower curve (which represents the Equation of Time) is produced by the simultaneous action of the two unequal periodicities shown separately above. By harmonic analysis it is possible to disentangle such inter-acting fluctuations by a study of the shape of the complicated curve which results from their combined effect. The method has been applied with good results to the light-curves of the long-period variables.

The problem underlying the whole matter is that of producing a photographic plate which will have the same relative sensitiveness to colour as the human eye possesses. Prolonged research, especially in America, has lately provided the solution of this problem, and it is now possible, by staining the plate with certain dyes and by photographing through a coloured screen, to produce what are essentially visual effects by photographic means. The magnitudes thus determined are known as "photovisual," and the difference between them and the ordinary photographic magnitudes, is obviously a measure of the redness of the stars concerned. This difference, expressed in magnitudes, is termed the star's "colour-index."



From "Variable Stars."] [*By C. Furness.*

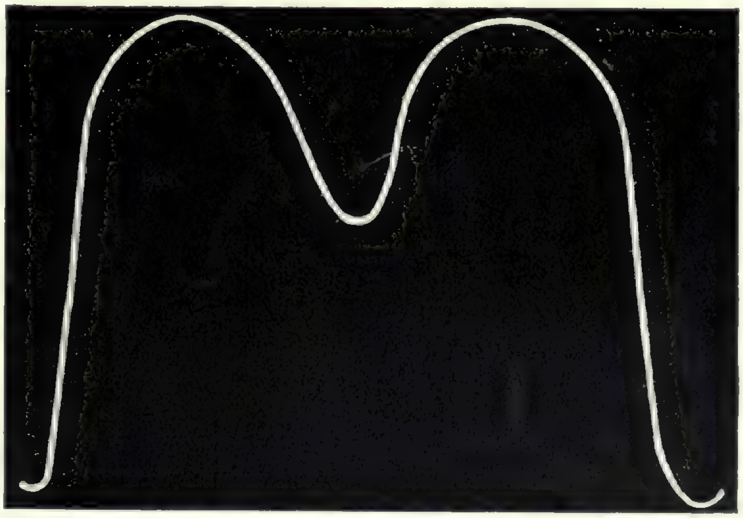
LIGHT-CURVE OF ALGOL.

This variable is of the "dark" eclipsing type, and consists of two stars of very unequal brightness revolving round their common centre of gravity. The near coincidence of their orbit planes with our line of vision causes mutual eclipses of the components. The greater and lesser falls in the total apparent light correspond with the eclipses of the brighter and darker star respectively. A diagram of such a system is given on page 521.

Before leaving the subject of photometry mention must be made of the recent introduction of two entirely new instruments for the determination of stellar magnitudes. Both depend in

their action on the same principle, which may be broadly described as follows. Certain metals have for many years been known to alter their electrical conductivity on exposure to light, the effect being termed "photo-electric." Laboratory experiments have made it possible to measure the relative intensity of light necessary for the production of different electrical changes, and so to find an empirical law by which the first can be deduced from the second. The application of this principle to the measurement of starlight seems obvious enough, but there are very considerable technical difficulties in the way. However, after much patient research, two satisfactory instruments, working on the photo-electric principle, have been evolved. The first is known as the selenium photometer, so called because its operation depends on the action of light on this metal. A thin film of the latter, with a steady electric current passing through it, is placed at the eye-end of a large telescope. The light of the star to be examined is now allowed to fall for a certain number of seconds on the metal. This alters its resistance to the current and the effect is discerned and measured by the reading of a delicate galvanometer. This sounds very simple, but the most elaborate precautions are necessary to ensure success, and this has deterred many from undertaking work with such an instrument. It has, however, yielded results of great value and importance in the hands of Stebbins, who was one of the first to apply photo-electric methods to astronomical problems.

The second successful photo-electric photometer depends on the action of light on the metal potassium, a film of which, enclosed in an exhausted glass bulb or "cell," receives the star's light, as was the case in the selenium photometer. This produces certain modifications in a continuous current passing through the cell, and the amount of disturbance (proportional to the intensity of the light) is registered on a galvanometer.



From "Variable Stars." By C. Furness.

LIGHT-CURVE OF BETA LYRAE.

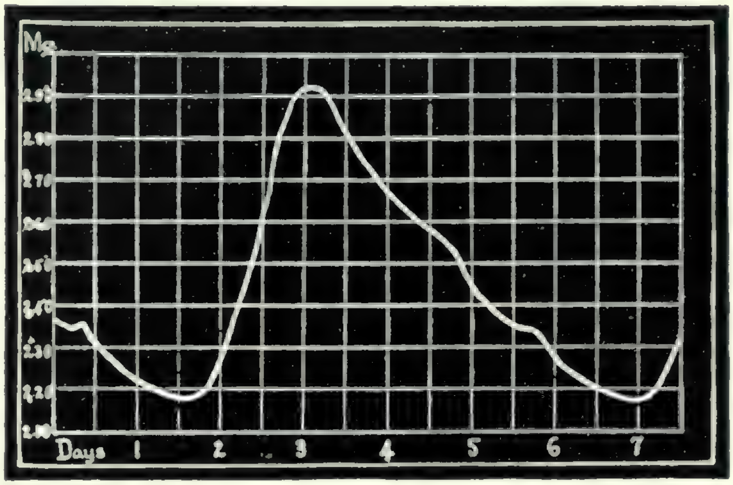
Beta Lyrae is typical of the class of "bright" eclipsing variables. The changes in light are due to the mutual eclipses of two stars of comparable luminosity, which accounts for the great relative depth of the "secondary minimum," seen at the centre above. The shape of the curve enables us to say that the two stars are very close together, and that each is elongated by the effects of tidal action. In both types of eclipsing variables the curves repeat themselves with "clockwork" regularity.

The great advantage of both instruments is their extreme sensitiveness. With either it is possible to record correctly differences in light corresponding to little more than $\frac{1}{200}$ of a magnitude. This is well in advance of the accuracy attainable by any other photometric method. The principal drawbacks are the great technical difficulties involved in the handling of the instruments and their present limitation to the brighter stars alone.

* * * * * * * * * * *

We must now turn from our brief review of photometry in general to that special branch of it which is concerned with stellar variability. As we have already seen, this phenomenon was scarcely, if at all, recognised in the early days of Astronomy, and no definite allusion to it has come down to us in ancient records. We have, however, good reason to believe that one star at least was known to be variable in its light as long ago as the early middle ages, if not earlier still. This star appears in our modern atlases under the designation of β Persei, and is not remarkable on account of its brightness, colour or position, being a very ordinary-looking white star of the second magnitude, and less conspicuous than several of its near neighbours. And yet the Arabian astronomers of the middle ages gave it the very

peculiar name of Al-Gol, or the "Demon." Such a designation is in type quite out of keeping with those which were allotted to the other stars, and it therefore seems highly probable that it was chosen to indicate some mysterious and "uncanny" characteristic which distinguished this body from all other members of the stellar host. It was not until 1669 that Montanari redirected the attention of astronomers to what was then regarded as an entirely new discovery. This observer noted that, while the star generally appeared as bright as the second magnitude, there were occasions on which it was fully a magnitude fainter. This announcement does not seem to have caused much excitement, though it was confirmed by Maraldi in 1694, and it was not until 1782 that the Englishman Goodricke, then eighteen years of age, made the first careful study of the star's variability.

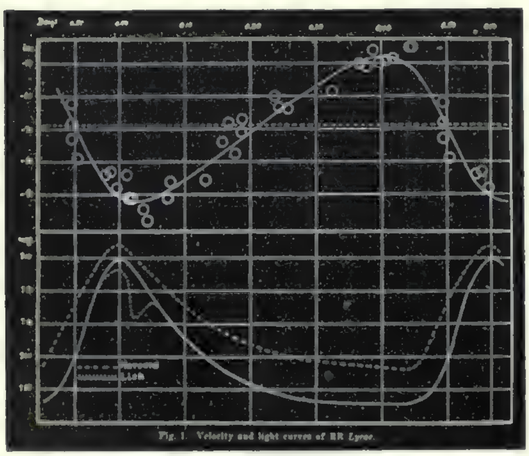


From "Variable Stars."] [*By C. Furness.*

LIGHT-CURVE OF DELTA CEPHEI.

This curve is typical of those of all "Cepheid" variables. It shows a rapid rise followed by a slower fall of light, and these changes are repeated indefinitely with perfect regularity. Stars of this type are yellow in colour, but the eclipsing variables are nearly all pure white. The exact cause of Cepheid variability is still in doubt.

The independent discovery of the changes of Algol by Montanari was not quite the first of its kind in comparatively modern times, for the beginning of the recorded history of stellar variability really dates from the year 1596, when Fabricius, a Dutch astronomer, noted the sudden appearance of a third magnitude star in Cetus, where previously no such object had been recorded. The star faded in a few weeks and was for some time reckoned among the "new" or "temporary" stars. In 1638, however, Holwarda again observed the star, and this time the important fact was noted that, after disappearing as before, it again became visible eleven months later. Moreover, it was evident that it must have been visible (for a time at least) thirty-five years before, when Bayer catalogued it under the name ο (omicron) Ceti. The manner of its variability is different from that of Algol, for, while the latter is normally at its brightest and only fades at intervals for a few hours, ο Ceti is generally invisible to the naked eye except for short periods many months apart. Also in its orange-red colour it contrasts with the pure white of Algol. Two more variables were discovered by Goodricke; namely, β Lyrae and δ Cephei. The behaviour of the former (which is white in colour) appeared at first very similar to that of Algol, but closer observation showed that the amount of its periodic fading was not constant, being alternately large and small. δ Cephei is yellow in colour and in its variability differs from the three stars already mentioned in being in a state of

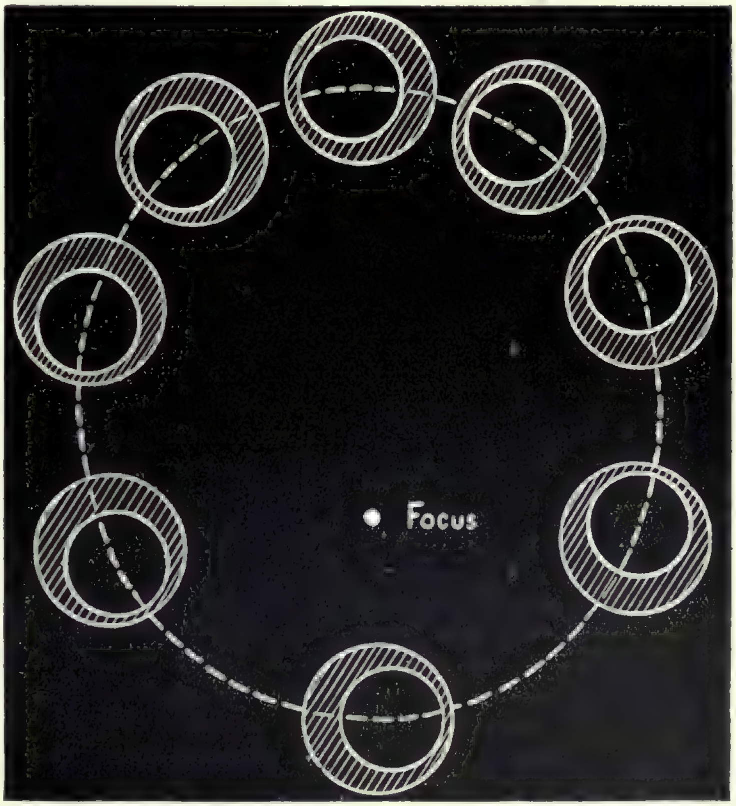


VELOCITY AND LIGHT CHANGES OF A CEPHEID.

The lower curves represent the changes of light as observed at two different stations. The upper curve shows the corresponding velocity of the star or its atmosphere as revealed by the spectroscope. The lowest point on this curve indicates the maximum speed of approach, which is seen to coincide very closely in time with the star's greatest brightness, as shown in the lower curve. The reverse holds good for the period of least brightness. This correspondence shows that the variability of the Cepheids is intimately connected with motion of some sort.

constant change, never remaining of the same brightness for any length of time. The changes are of quite a regular " up-and-down " nature, and occur always at the same intervals of time. These four important variables will be referred to again in detail later on. They were among the very few (only eleven) whose changes had been definitely established and studied up to the end of the Eighteenth Century. Since that time a few more bright stars have been shown to be variable, but the great bulk of discoveries of this nature has been among the fainter and telescopic stars.

Variables are brought to light in a number of different ways. In some cases they have been deliberately sought for by repeated observation of the same portions of the sky, but more often, in the early days at least, they were discovered accidentally in the course of the preparation of star catalogues and charts, and in the subsequent comparison of these with the heavens for various purposes. In the latter case the finding of bright stars not catalogued, or the failure to find some that are, has often led to further investigation and the eventual detection of variability. In more recent times photography has done great service in revealing the presence of new variables ; in fact most discoveries of this kind are to-day made by photographic means. At Harvard College Observatory in particular the constant repetition and comparison of small-scale photographs of the sky have brought to our knowledge many hundreds of variables, and the number is being added to year by year. Many thousands are now known, but of these only a few hundred have been adequately studied.

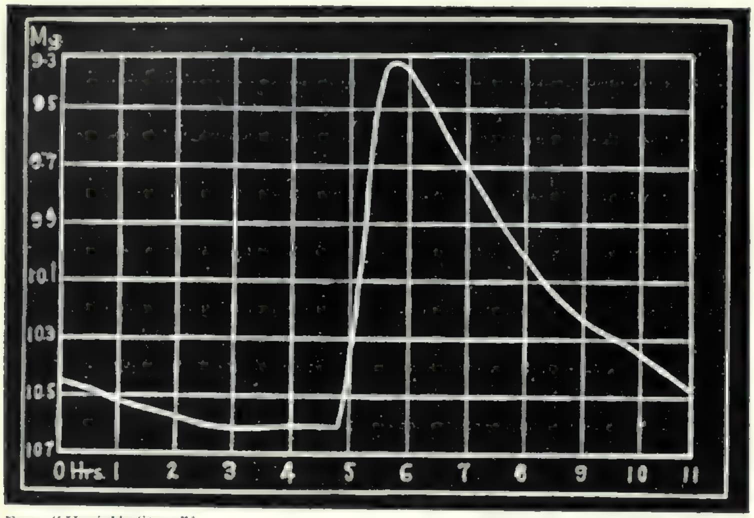


From " Variable Stars." [By C. Furness.

A THEORY OF CEPHEID VARIABILITY.

It has been suggested that the variability observed in the Cepheids might be explained by supposing the revolution of a star with a dense atmosphere round some dark controlling mass, widely surrounded by a resisting medium. The latter would tend to brush back the star's obscuring atmosphere on the " forward " side, thus producing an increase of light at the time when the motion is directed towards us. This would cover the observed correspondence between velocity and light change.

Something must now be said with regard to the methods employed in the observation of variables and the deductions that are possible from the data obtained. The first requirement is a series of observations of brightness, made on different occasions, which shall give as nearly as possible a continuous record of the changes occurring in the star's apparent magnitude. Naturally, if the variation is rapid the observations will require to be relatively more frequent. The methods of measuring the magnitude of a variable are essentially the same as those used in the case of stars of fixed brightness, but in choosing the one most suitable much depends on the type of variable concerned. Those whose change of brightness is small and rapid require very accurate observation, and for these photographic means or delicate photometers, such as those already described, are necessary for the best results. On the other hand a large number of variables change but slowly and through so wide a range of magnitudes (from one to six or more) that somewhat less accurate and frequent observations are required. In such cases, which



From "Variable Stars."] [By C. Furness.

LIGHT-CURVE OF A "CLUSTER" CEPHEID.

Cepheid variables have been found in relatively great numbers in some of the globular clusters. Their periods are much shorter than those of the isolated stars of which δ Cephei is the type, being only a few hours in length. They have been relegated to a class of their own (*i.e.*, the "Cluster" Cepheids) by the arbitrary adoption of an upper limit of twenty-four hours for their periods. Those of longer period are reckoned among the "ordinary" Cepheids.

include all the "long-period" variables, the magnitude is determined by simple eye-estimates. Such estimates are not, however, "absolute," but are made by careful comparison with the neighbouring stars, whose light is assumed to be constant. The first thing to do, then, is to determine once and for all the magnitudes of these "comparison stars," and this may be done (in the various ways already described) either by the observer himself or by some public observatory that is concerned with such work. The brightnesses of the comparison stars for most of the better known variables have been measured at Harvard, Rome, and elsewhere, and are available for use by any worker requiring them. Armed, then, with a chart of the field and a list of the magnitudes of the comparison stars, the observer is now ready to commence work. Two methods are, in general, open to him. The first, devised by Argelander, is known as the "step" method, and consists in judging directly the difference in brightness between the variable and various stars as nearly as possible equal to it in brightness, using as unit the smallest detectable difference. This unit (or "step") will vary slightly in value for each observer, who must find by experiment the value of his "steps" in terms of the accepted scale of magnitudes. In practice, experienced observers are so accustomed to the decimal division of magnitudes that they often make their estimate direct in tenths. In other words, they are able with some certainty to fix the value of their "steps" as $0^{M}\cdot1$, and this simplifies matters considerably. Otherwise each "step" estimate has to be translated subsequently into its true value in terms of magnitude. This "direct" or "step" method is very efficient where the difference to be estimated is not great (say over $0^{M}\cdot5$), but it often happens that none of the comparison stars is near in brightness to the variable, and in this case it is preferable to use the "fractional" method, developed by E. C. Pickering at Harvard. This consists in mentally dividing the interval of brightness between two comparison stars (one brighter and the other fainter than the variable) into ten or a smaller number of parts, and then estimating at what point in this scale the variable should be placed. Thus, it may be estimated to be just half-way between the two, or two-thirds of the way from the fainter to the brighter, or three-fifths from brighter to fainter, etc., as the case may be. The real difference between the two comparison stars is now referred to on the list of magnitudes and the value of these arbitrary subdivisions easily deduced.

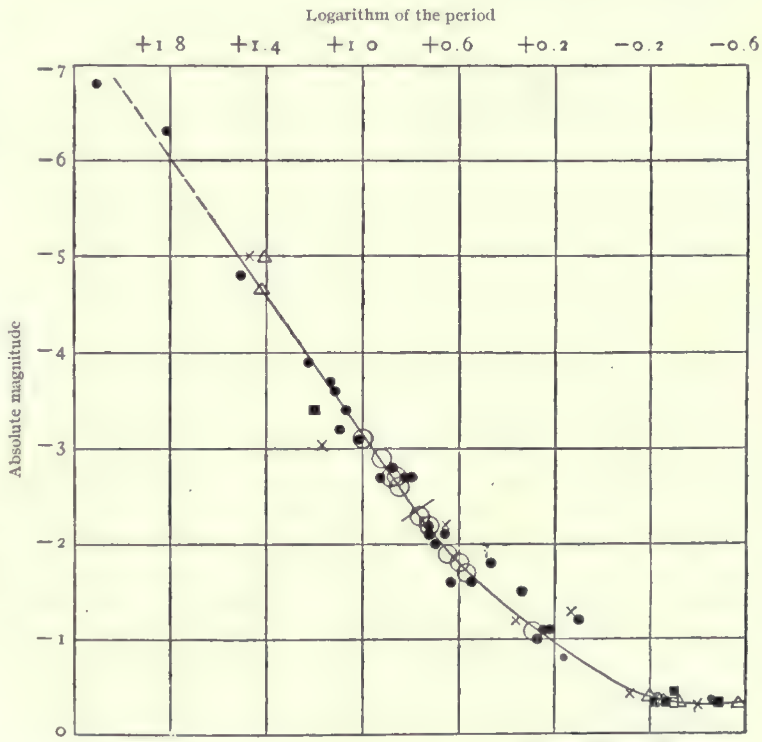
Having secured a series of observations, the next thing to do is to construct a "light-curve." This is done in exactly the same way as a patient's temperature is recorded on a clinical chart, the magnitudes (like the temperatures) being plotted vertically and the time horizontally. It is on curves thus drawn, coupled with contemporary spectroscopic observations, that all our knowledge of variable stars depends. And the amount of information that can be derived from such apparently meagre data is not a little astonishing. In a light-curve we have the means of studying three things: (1) The amount, (2) the period, and (3) the character of the star's variability. The first two are generally obvious enough in a good set of observations, for we are dealing with a series of "waves" whose height at once gives the

range of variation, and the length from crest to crest its duration or period. Often, however, both are themselves variable, so that a simple and final statement of the value of either is not immediately possible. But most important of all three features is the " character " of the variation. This is deduced from the shape of the waves and of their component parts. Obviously all information derivable from a light-curve must necessarily be confined to the relations existing between change in light and time elapsed, but even within these limitations we are able to glean much detailed information, for we can see by a glance at the curve whether the changes are regular or irregular, slow or rapid, simple or complex, temporary or permanent. All these factors are of value in enabling us to form theories as to the true underlying *cause* of the variation, which is, of course, our principal object in observing these bodies.

We have seen in our preliminary description of a few of the earliest known variables that there are marked differences in the type of variation exhibited by different stars. This leads to the necessity of attempting some kind of classification of the variables known to us, and, in fact, many such attempts have been made in the past. The problem is by no means a simple one. Undoubtedly the most rational classification would be one that was based on the causes of variation, but, since we are in most cases still quite ignorant of these, such a classification is at present impossible, though we look forward to its realisation in the future. We have therefore to fall back upon the purely apparent characteristics of the star, as exhibited in its light-curve and in the nature of its radiation as revealed by eye and spectroscope. No really satisfactory classification has yet been made, and admittedly each one is to some extent arbitrary.

The one here adopted is subject to this defect. It has proved convenient in use, and is probably in many respects a logical one, but much of it is still provisional and it must not be taken as indicating that we have finally put each of these mysterious bodies into its proper place.

Broadly speaking, variable stars can be divided into two main groups, according as their changes of light are *regular* or *irregular*. But at best the distinction is far from being a rigid one, for while at one end of the scale we have variations of *absolute* regularity and at the other end changes which seem quite evidently devoid of all true periodicity, there is a large number of intermediate grades which are neither altogether regular nor altogether irregular. Thus in many that are in the main regular there is something that just disturbs their complete regularity, while in others which appear at first sight to obey no law there are certain features that indicate at least a slight



[*Mount Wilson Observatory.*

PERIODS AND REAL LUMINOSITIES OF "CLUSTER" CEPHEIDS.

Many of the Cepheids are sufficiently near to us to have their distances measured with considerable accuracy. From this we can, knowing their apparent brightness, easily calculate their true or " absolute " luminosities. These latter are found to bear a definite relation to the length of the period, as shown by the curve above. Having established this, we can reverse the process, and deduce from the observed period the absolute luminosities (and therefrom the distances) of any star of this type. Upon this depends our knowledge of the great distances of the globular clusters.

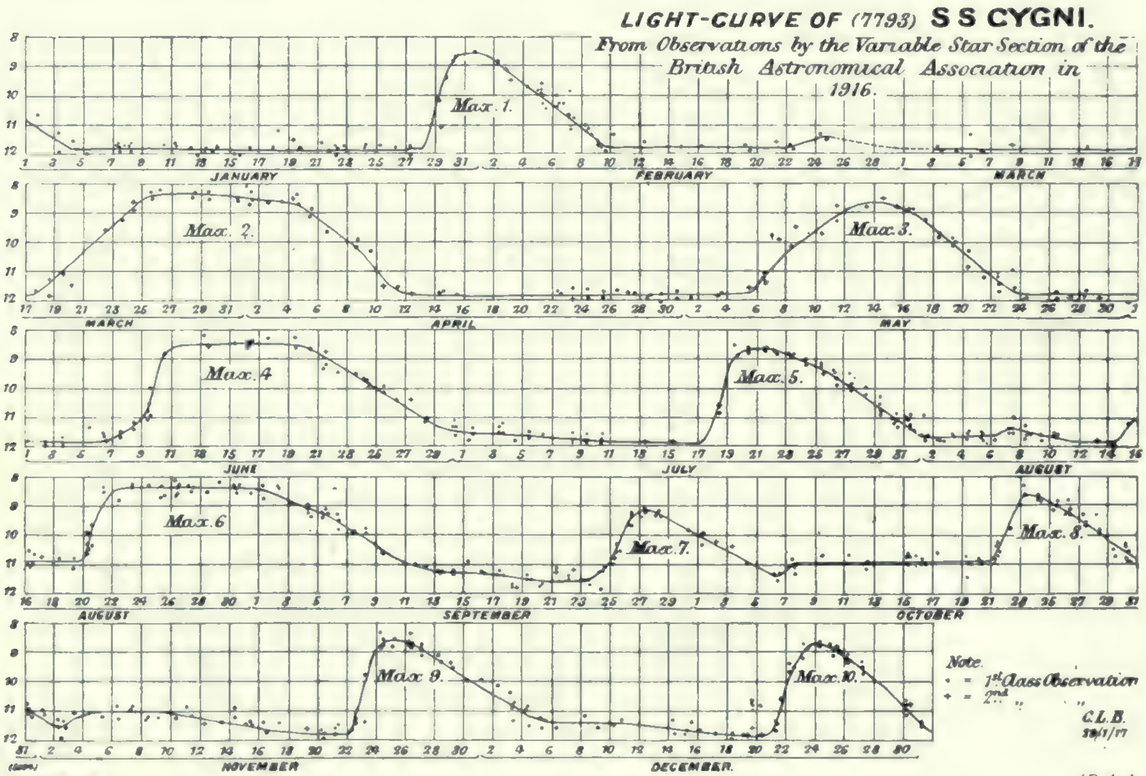
element of regularity. For these reasons the main brackets in the table below have been purposely made to overlap.

CLASSIFICATION OF VARIABLE STARS.

Character of Variation.	*Period.*		*Typical Star.*
Regular ...	Short Period	(*a*) " Dark " Eclipsing... ...	Algol.
		(*b*) " Bright " Eclipsing ...	β Lyrae.
		(*c*) Cepheids	δ Cephei.
		(*d*) " Cluster " variables ...	Hundreds known in globular clusters.
	Long Period	... ...	o Ceti.
Irregular ...	No definite period (changes at long and short intervals).	(*a*) Faint with occasional rises	S S Cygni.
		(*b*) Bright with occasional falls	R Coronae.
		(*c*) Long continued irregular changes.	η Argûs.
		(*d*) Single gigantic outburst followed by fading.	Nova Persei.

It now remains to give a brief description of the characteristics of each of the above types, with the various theories that have been accepted or suggested to account for the phenomena observed.

The first two classes on the list of Short Period Variables may conveniently be treated together, for reasons which will presently appear. It so happens that they are the only two types of whose explanation we are reasonably certain. We will first of all consider the Algol variables. A glance at the light-curve



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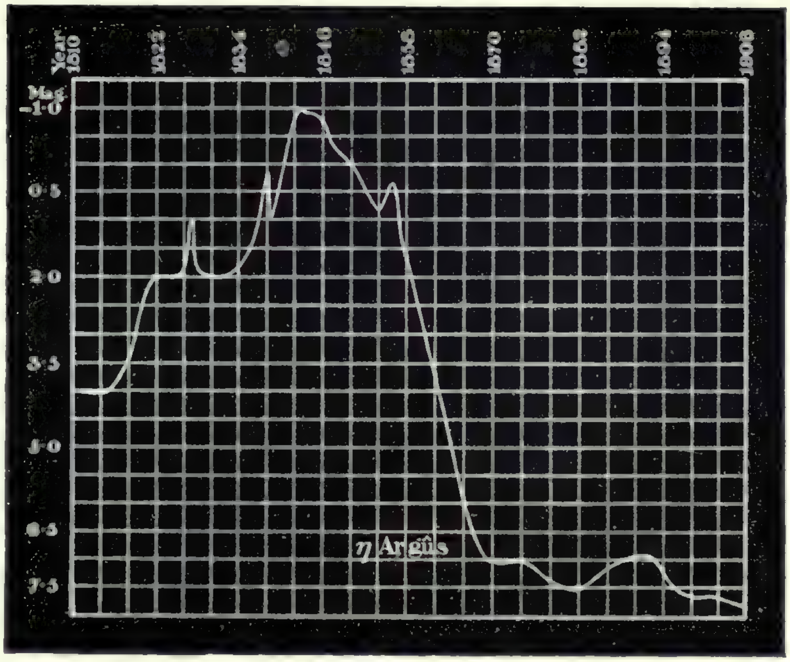
LIGHT-CURVE OF SS CYGNI.

This type of irregular variable is only roughly periodic in its changes. It is normally faint, but rises abruptly at irregular intervals and to an unequal extent. Two kinds of maxima, of long and short duration respectively, tend to occur alternately; but this is not a constant rule, as will be seen by inspection of the curve above.

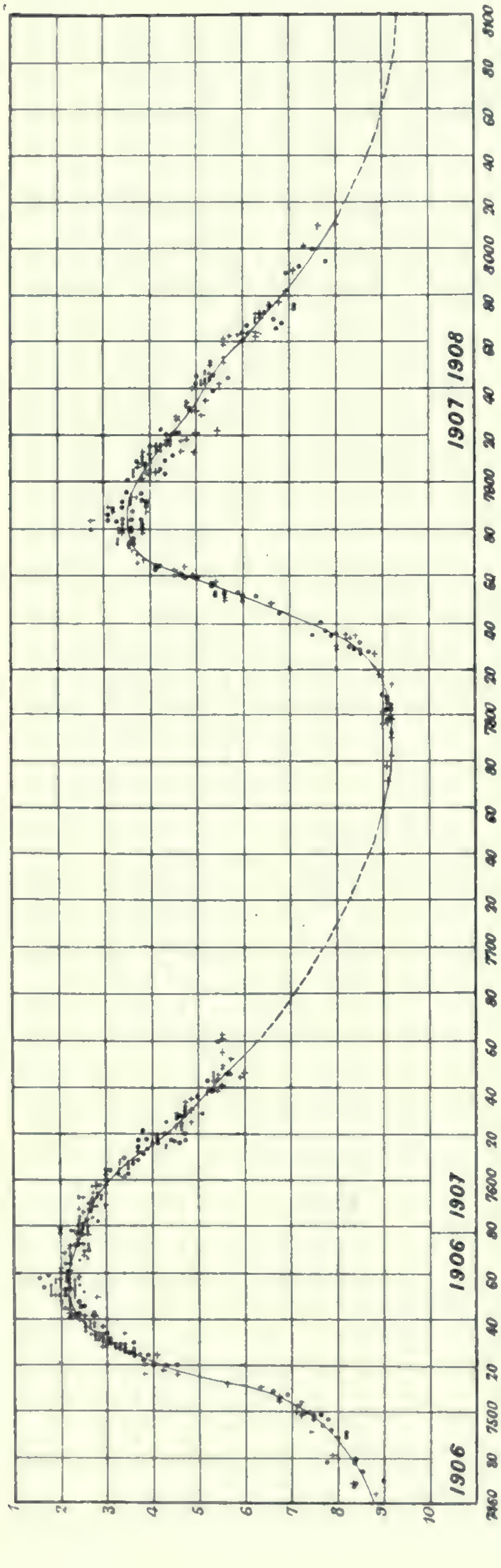
of the typical star (p. 592) will show that it indicates a generally steady condition of brightness broken by short abrupt falls at perfectly regular intervals. A plausible explanation of so simple a curve is not hard to find ; in fact, Goodricke himself, as long ago as 1783, was not afraid to hazard the obvious suggestion that we are here witnessing the periodic eclipse of a bright body by a dark one. But, in the condition of astronomical knowledge at that date, this could only be regarded as a likely guess, and it has remained for modern researches to prove its correctness. The light-curve shows that the loss of light during each fall amounts to two-thirds of the whole. Evidently, then, the dark companion must be at least comparable in size to the bright star. Now, this being so, the Law of Gravitation demands that we should rid our minds of the conception of a "stationary bright star with a dark star revolving round it," for both, if comparable in size, must also be comparable in their rate of motion round their common centre of gravity. Hence we should expect to be able to detect the orbital motion of Algol by a spectroscopic examination of his light, according to Doppler's principle ; and this is exactly what we find, the light-curve and radial velocity confirming one another with perfect accuracy. But we are still left somewhat in the dark with regard to the star's mysterious companion. From Goodricke's time up to 1910 it was always confidently referred to as a " dark " body, because when according to theory its turn came to be eclipsed by its bright neighbour no diminution of the total light could be detected, and it was therefore concluded that there was no light to be diminished. However, the sensitiveness of the selenium cell enabled Stebbins to detect a minute fading, amounting to scarcely more than $\frac{1}{20}$ of a magnitude, at the point where the " dark " star must suffer eclipse. This little fall is spoken of as the " secondary minimum," to distinguish it from the principal decline, or " primary minimum."



LIGHT-CURVE OF ETA ARGÛS.

This star, which is not visible in northern latitudes, is one of the most remarkable variables in the sky. Its changes have been altogether capricious and appear to be in no sense periodic. In 1843 it was for a time almost the brightest star in the heavens, but it is now invisible to the naked eye, and has long remained between the seventh and eighth magnitudes with little variation. Its spectrum consists of bright lines, and the star itself is situated in the midst of a great nebula.

A large number of variables of the Algol type is now known, and a parallel study of their spectra and light-curves reveals many interesting details which cannot be entered into here. It will suffice to state that we are able to form very close estimates of the diameters, surface-brightness, masses and densities of the two bodies involved in each case, and can determine the elements of their orbits and their inclination to our line of sight. All these features are subject to certain differences as between one variable and another, but there is a general similarity between all those that have so far been observed. Thus, all are white stars, with spectra ranging from B to F, the majority being of type A. The periods are all less than thirty days, with the majority between one and five days, and the total range of brightness is between one and two magnitudes. All may be considered as a special class of double stars, with components of unequal brightness. The " dark " component is, in general, somewhat



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LIGHT-CURVE OF MIRA (OMICRON) CETI.

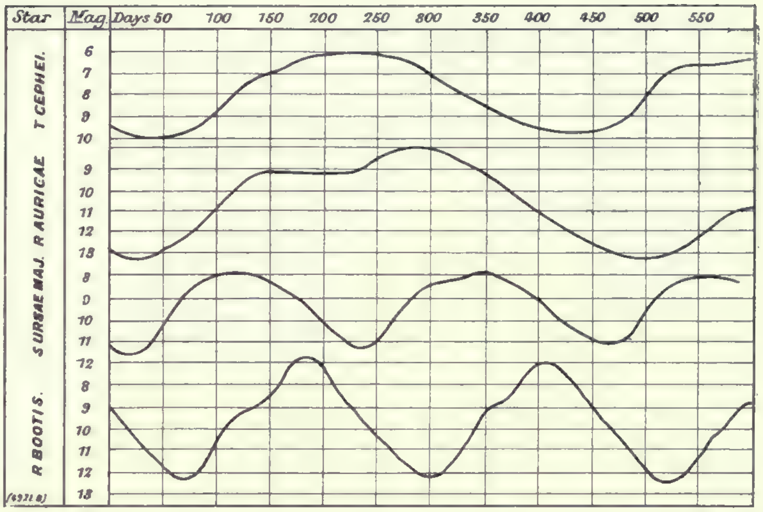
This is the first-discovered and most famous of the long-period variables. It goes through its changes in about 331 days, but, like others of its class, exhibits some irregularities of period and range. The difference of height and shape of the two maxima here shown will be noted. This diagram illustrates the method of drawing a light-curve through the combined observations of a number of workers. Thousands of such observations are made yearly by the members of the British Astronomical Association.

the larger and less dense of the two, but it is perhaps desirable to emphasise by repetition the fact that the "darkness" is relative only, many of these bodies having "absolute" luminosities greater than that of our Sun.

Turning to the variables of which β Lyrae is the type it might seem, from a casual inspection of the light-curve on p. 593, that we were here dealing with bodies very different from Algol in their behaviour. A closer study, however, will show that the difference is not after all very great. We have, as in the Algol stars, two minima, but in this case the second one is relatively much more pronounced, and in certain cases is of practically the same depth as the first. But for this greater equality of the minima there is no other outstanding difference between the two types, except that in the β Lyrae stars the variation is *continuous*, as is shown by the absence of horizontal sections in the light-curve. The first of these differences is readily explained by the supposition of the mutual eclipses of two *bright* bodies whose relative brilliance is to be deduced from a comparison of the depth of the minima. This supposition has been abundantly confirmed by the spectroscope, which reveals to us the presence of two bright stars in orbital motion round their common centre of gravity. So far, then, we may take these variables as differing from the Algol stars only in the relative brightness of the components. But a further distinction is brought out by the continuity of change already alluded to. This could only be reasonably explained, in the case of spherical bodies, by their being in contact with one another, so that one eclipse would follow straight on the other; but a careful study of the curve shows that this is not so, and the difficulty has been got over by assuming each body to be elongated by tidal action in the direction of its neighbour. In such a case the two would always turn the same face to one another, like waltzing partners, and the area of each presented to our view would be constantly changing in amount, thus producing the continuous variation

observed. The known fact that the bodies are very close to one another serves to strengthen, and even make certain this conclusion as to their distortion by tidal action. Most of the β Lyrae stars are white, like the Algols, and are of spectral types B or A. Their periods are also of the same order, though on the average somewhat shorter, and their range of variation is generally slightly smaller.

In a previous chapter reference was made to the existence of spectroscopic binaries in which either one or both of the components were distinguishable. It is now generally held that Algol and β Lyrae are merely special cases of these two types of binary, distinguished from them only by the fact that the planes of their orbits happen to lie in our line of sight.



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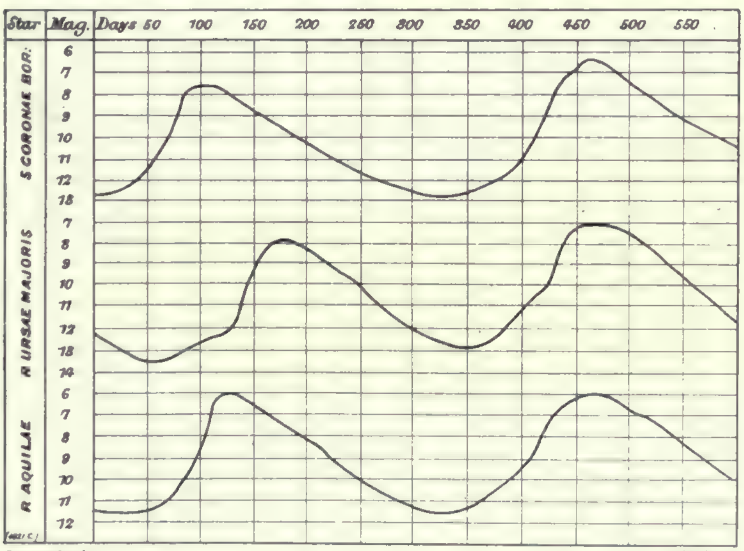
LONG-PERIOD VARIABLES OF "GROUP I." (PHILLIPS.)

Mr. Phillips' classification of long-period variables according to the results of harmonic analysis reveals the existence of two "groups." In the first come the stars which rise and fall in nearly equal times, with a tendency to pause during their increase of light.

The two remaining classes of short-period variables, "Cepheid" and "Cluster," are, like the first pair, best treated together; in fact, they may in many ways be considered as essentially identical in type. They differ, however, from the eclipsing variables in several important respects. In the first place their light-curves bear no resemblance to those of Algol or β Lyrae, as will be seen by an inspection of the curve of δ Cephei (p. 594), the star that gives the class its name. Here we have a continuous variation, characterised by a rapid rise followed by a gradual fall, and only one definite minimum. The periods of the brighter Cepheids vary from one to about thirty days, but most are about a week in length. The range of variation does not, in general, exceed one magnitude. In colour these stars are yellowish, being mostly of type G, like our Sun, and this fact serves to distinguish them still further from the variables so far described. A study of the light-curves alone is hardly a sufficient basis for theorising as to the cause of Cepheid variation, and we must here again appeal to the evidence furnished by the spectroscope. This instrument can do no more



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LONG-PERIOD VARIABLES OF "GROUP II." (PHILLIPS.)

The stars belonging to this group are characterised by a relatively rapid rise in light, followed by a much more gradual fall. This is shown by the steepness of the "waves" on their left, or rising, sides. The famous variable, Mira Ceti, is a member of this group.

than tell us that, just when a Cepheid is at its brightest, *something* (either the star itself or its atmosphere) is approaching us, to recede again as the variable reaches its minimum. Now there is still much division of opinion among astronomers as to the interpretation of this, and we are still without a really satisfactory theory to account for the phenomena observed. Many suggestions have been put forward but we will here mention only two. The one is that we are observing a bright star revolving in a very eccentric orbit round a dark controlling body, while a resisting medium brushes away the star's atmosphere on the forward side, giving rise to its increase of light when approaching us. Such a theory has seemed to many a little far-fetched ; and there are several objections, one of which is the invariable absence of " eclipse " effects such as would be caused by the presence of a second body in certain inclinations of the orbits. To get over these difficulties we have the alternative suggestion of Shapley that we are here concerned with periodic pulsations in the atmosphere of a single star. Until recently this explanation seemed almost as improbable as the other, but the interferometer measures suggesting a similar pulsation of the great star Betelgeuse make it appear less fantastic than it seemed at first. At present, then, we can say no more with certainty than that the variations of the Cepheids are, like those of the eclipsing variables, closely associated with *motion*, but how far such motion is a cause or effect of the variability we are not in a position to tell.

POSITION OF NOVA PERSEI.

The bright new star of 1901, which for a time was the most brilliant star in the northern sky, was situated in the constellation Perseus, not far from the famous variable star Algol. The nova is now only visible in a powerful telescope.

The " Cluster " variables are essentially Cepheids of short period and low apparent magnitude. They derive their name from the circumstance that they are found in large numbers in some of the globular clusters. Actually there is no sharp dividing line between them and the Cepheids proper, but Shapley has suggested an arbitrary distinction according to period, classing among the Cluster variables all Cepheids whose periods are less than one day. The great importance of the Cluster Cepheids has already been pointed out in Chapters XI and XIV, where we have seen how the relation existing between their periods and absolute magnitudes has enabled us to estimate the otherwise immeasurable distances of the globular clusters.

TYCHO'S STAR OF 1572.

This was one of the most brilliant of the temporary stars, or Novæ, ever observed. Like others of its kind, it burst out with great suddenness in the course of the Milky Way. At its brightest it outshone Venus and was visible in full sunshine. It soon began to fade, but could be seen with the naked eye for seventeen months.

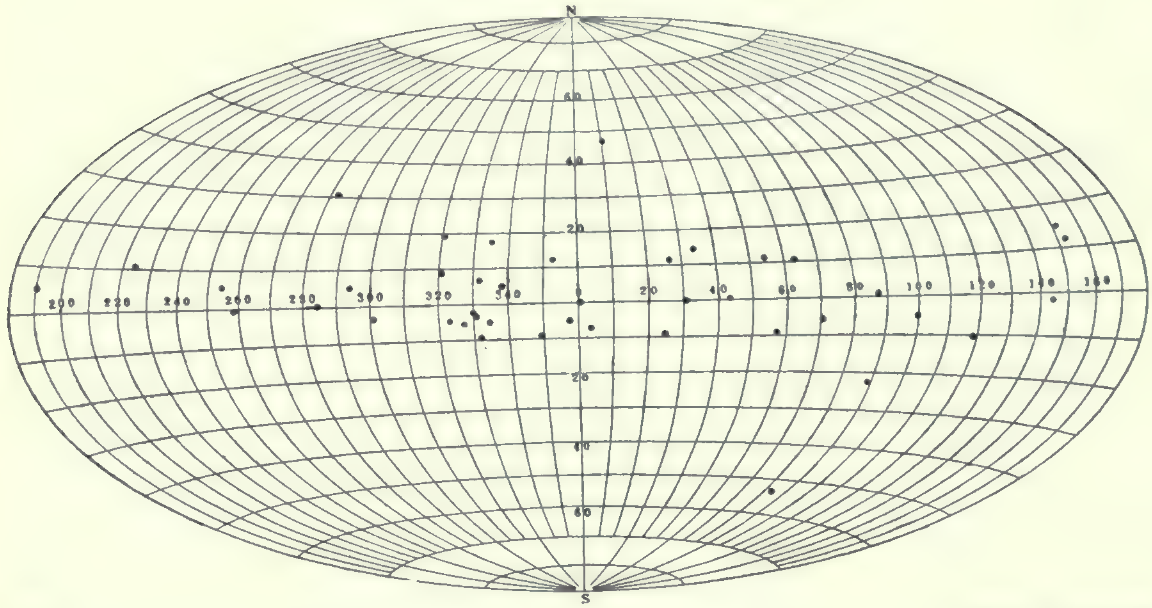
The next class of objects on our list is an important one, for it embraces the great majority of all the variable stars known to us. The " Long-Period " variables, as they are generally called, differ in almost every particular from the bodies just described. An outstanding, though not perhaps the most important, distinction is that which gives them their name ; for, while the stars so far described go through their changes in the course of a few days, or even hours, the periods of the variables we are now considering range from 50 to over 600 days. The

amount of variability is also considerably greater in nearly every case. The total range of magnitude varies in different stars from just over one to more than nine magnitudes. There is a rough relation between period and range, the latter tending to increase with the former. The majority have periods of between 200 and 400 days, and a total range of about five magnitudes between maximum and minimum. Nearly all the long-period variables are, unlike those of short-period, reddish stars of spectral type M, and it appears likely that most of them are giants. There seems to be some vague relation between redness and length of period, the one increasing with the other. These, then, are the more simple characteristics of the variables of long-period. But when we come to examine the *manner* of their variation, as shown by their light curves, it becomes less easy to generalise. An inspection of a few such curves will show where the difficulty lies. We can say of the curves of Algol, β Lyrae, and δ Cephei that they are typical of *all* the stars in their respective classes, and we can classify any one of these by the characteristic shape of the curve alone. But in the case of the long-period variables there are great differences in the shapes of the individual curves, so that we cannot point to any one as characteristic of the class as a whole. And yet it seems certain, from other considerations, that we are dealing with stars that must be considered as of essentially one type. If this is so, the differences observed in the shapes of the curves point merely to the existence of factors which tend to modify the curves within certain limits, and produce at least an apparent subdivision of the class. So far, the most successful attempt to subdivide the long-period variables on the evidence of their light-curves was that made by T. E. R. Phillips in 1916. His method was primarily a mathematical one, and it is impossible to give it here in detail, but the simple principles on which it is based are quite easily understood. A repeating curve (such as those of the long-period variables approximately are) may be assumed to be the summation of a number of subordinate "waves" or harmonics, the shape of the light-curve as a whole depending on the amplitudes and phases of these separate "waves." Now it is possible by a mathematical process known as "harmonic analysis" to disentangle these factors which in combination produce the characteristic light-curve of a star, and the data thus derived are available as a means of classification. Moreover, if two or more causes of independent variability of periods are operating, they will modify the curve in what may appear at first sight a very irregular way. It is possible to disentangle such factors too, and to find the period and amplitude of each. Now, the light-curves of the long-period variables, though approximately regular, exhibit definite departures from perfect similarity in their individual "waves." These apparent anomalies show themselves

From "Astronomy for All."] [*By permission of Messrs. Cassell & Co., Ltd.*

TYCHO OBSERVES HIS STAR.

The star of 1572 was first seen on November 11, and was probably "discovered" by many persons simultaneously. It is, however, always associated with the name of Tycho, who made a special study of it and wrote a detailed description which has come down to us. Two faint telescopic stars still exist near the place which he deduced for the Nova, but it is not certain that either is identical with it.



From [" *Popular Astronomy*."

DISTRIBUTION OF NOVAE IN THE SKY.

This chart shows the positions of forty-two of the brighter Novae observed since 1572. The central horizontal line represents the plane of the Milky Way, and it will be noted that the great majority of the Novae have been situated within or very near this great structure, which is, in some places, about twenty degrees in breadth. It has been observed that New stars tend to appear at the edges of the dark spaces rather than in the midst of the bright parts of the Galaxy.

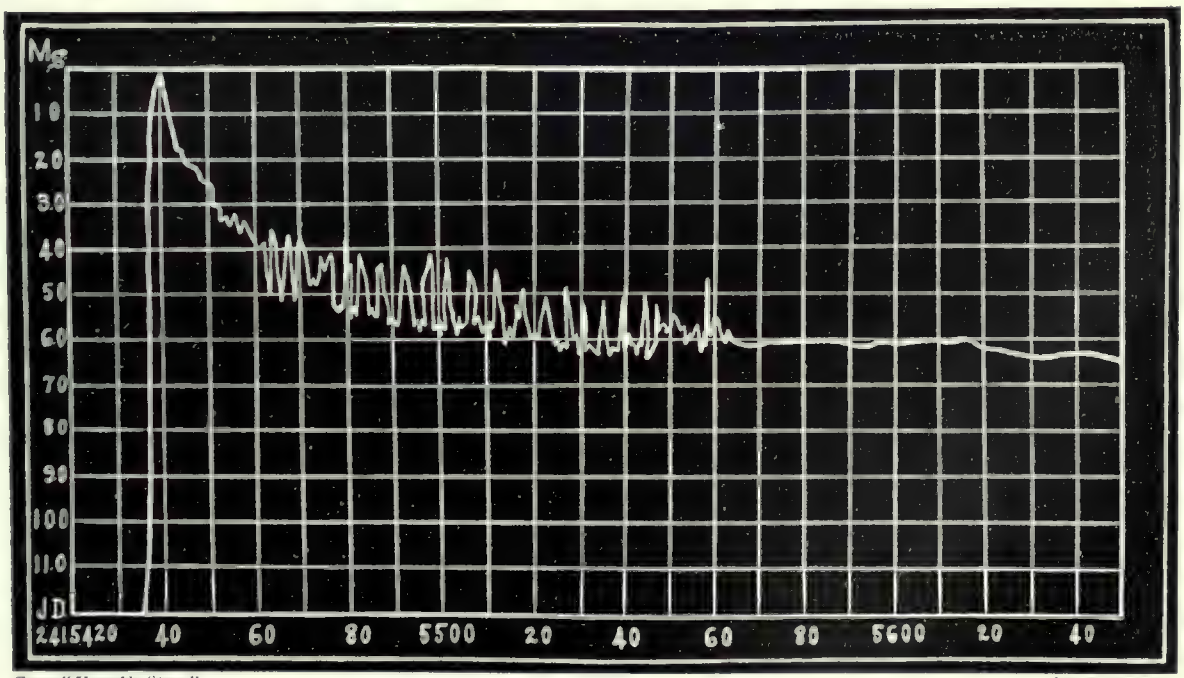
by slight differences of period and amplitude, and by modifications in the shapes of the different undulations. Such a condition of things lends itself to study by analytical methods, and work on these lines by various investigators has led, in the case of individual stars, to the construction of formulae that will cover the combined effect of some of these inter-acting periodicities. Mr. Phillips treated the subject in a statistical way, analysing the mean light-curves of a large number of long-period variables harmonically. As a result of his research he was able to state that the variables so treated fell into two distinct groups, distinguished by certain mathematical relationships between the factors responsible for the shapes of the curves. It so happens that these differing relationships produce a visible effect in the resulting light-curve, so that the distinction can be readily grasped by the non-mathematical reader. Briefly, it may be said that in the variables of Group I the rise and fall of light occupy nearly equal periods, while there is a tendency towards the occurrence of a pause in the rising portion of the curve. In Group II, on the other hand, the stars rise in light more quickly than they fade, so that the waves are much steeper on their ascending sides. The difference between the two groups will be obvious from an inspection of the diagrams on p. 601.

Nothing has yet been said as to the probable cause of variability in these stars. As a matter of fact no really satisfactory theory has ever been put forward. The spectroscope shows us that the variation of light, whatever its cause, is certainly not due to motion of the star as a whole, as was the case with Algol and β Lyrae. This seems to dispose of an old theory that the rise of light was due to periodic passage through a swarm of meteors. On the other hand, the same instrument gives definite evidence of an eruption of hydrogen at a high temperature about the time of maximum brightness, and this fact, taken with others, has led to the general opinion that we must look to causes operating in the star itself for an explanation of the observed variability. At present it looks as though some sort of pulsation or intermittent explosion due to accumulating excess of pressure were responsible, but we are far from having reached certainty on this point, and much further study of these bodies is required. An outstanding difficulty is the great *magnitude* of the changes as compared with the shortness of their duration. What seems almost inconceivable is that a star should

increase its *real* brightness several hundred times in a few weeks and yet be able to return to its normal condition in well under a year, as if nothing had happened. One would have expected such a mighty change to be almost catastrophic in its results, and that rapid recovery would be impossible. Yet, apparently, this is what happens.

We must now pass on to the so-called "Irregular" variables; by which we mean stars whose changes either appear altogether capricious, or take place at such unequal intervals that we are so far baffled in our attempts to find any governing principles underlying them. Taking the second class first, we find two distinct types of variable of what may be termed a semi-periodic character. They are, in fact, often classed with the long-period variables, though far less regular in their behaviour. Stars of the first type are normally faint, but undergo short-lived increases of light at irregular intervals. Sometimes, as in S S Cygni (the typical star of this kind), two varieties of maxima, long and short, are observed, and these have a tendency to recur alternately, as will be seen from the curve on p. 598. Usually the rise is more rapid than the fall, but this is not always so. The second type of star is normally bright, but fades at irregular intervals, and often oscillates in its light before rising again. R Coronae is typical of this class. The invariable downward tendency of the changes is suggestive of temporary obscuration by occulting matter, but it cannot be said that any satisfactory explanation has been given to account for the variability either of this or the first type. Very few stars of the kind have so far been studied, but it seems that in range of apparent magnitude they closely resemble the long-period variables, though they are less uniformly red, two at least being F type stars.

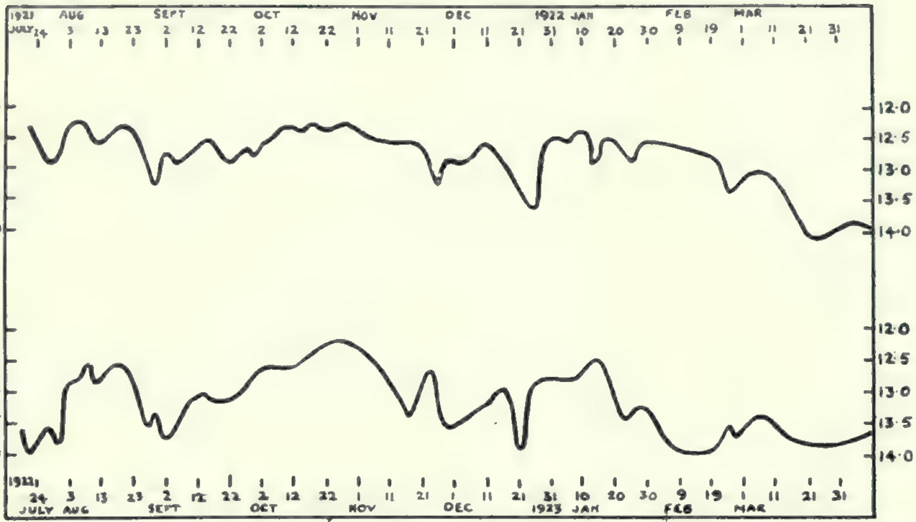
There remain certain stars which exhibit changes of an entirely capricious character. Such changes may be great or small, rapid or slow, but they do not appear to be of a truly periodic nature. Betelgeuse and α Herculis are examples of stars that occasionally pass through rapid changes amounting to less than one magnitude, while the best known instance of a slow and considerable variation is afforded by η Argûs. This star, which is not visible in northern latitudes, was observed by Halley



From "Variable Stars." [*By C. Furness.*

LIGHT-CURVE OF NOVA PERSEI, 1901.

This curve shows the very abrupt initial rise of light, amounting to over twelve magnitudes in a few days! Then comes the fall, rapid at first but more gradual later. The remarkable series of undulations during a part of the fall is clearly shown, but the latter part of the curve is much more smooth. The vertical lines represent intervals of ten days.



LATER LIGHT-CURVES OF NOVA PERSEI.

The general fading of this Nova has long ago ceased, but its light is by no means constant. As will be seen from the above curves, which show its variations in 1921, 1922, and 1923, it has a range of about two magnitudes and is seldom the same for more than two or three days together. The variability appears at first sight to be entirely irregular in character, but it is possible that further study may show that at least part of it is strictly periodic.

in 1677 as of the fourth magnitude. Between this date and 1800 it oscillated between this brightness and the second magnitude. In 1810 it began to rise rapidly, and reached zero magnitude in 1843, being therefore at that time two-and-a-half times as bright as an ordinary first magnitude star. Thereafter it steadily faded until 1870, when it had reached the seventh magnitude. At this brightness it has remained ever since with very little change. Its spectrum is peculiar, and appears to consist entirely of bright lines. The fact that this object is deeply involved in an extensive nebula is suggestive, and it seems more than probable that the changes in its light are in some way connected with this. We shall later have occasion to refer again to this likely connection.

* * * * * * * * * * *

The variable stars with which we have so far dealt have at least one feature in common, apart from their variability, and this is the fact that they are, like the more normal stars, permanently visible in the sky. Or rather, we can say that in nearly every case the average brightness of each has not altered appreciably since careful observations were first made of it. But in the face of so much that is changeable, it is natural to enquire whether there may not be examples of stars which have permanently disappeared, or of others that have come into being since the time when the Heavens were first accurately observed. In other words, have we ever witnessed the death of any old star or the birth of any new one ?

To the first part of this question it is difficult to give any decided answer. It is true that quite a large number of stars, mostly faint, recorded on charts and in catalogues in the past, are no longer to be found in the sky, and many have confidently asserted, on this negative evidence, that the death of stars is a demonstrated fact. On the other hand, every astronomer knows how very easy it is to make mistakes of recording and reduction, especially where a large number of objects is concerned, and, in fact, it is definitely known that in many cases such mistakes have led to the erroneous recording of stars which never existed. Then, again, Uranus, Neptune, and various Minor Planets have frequently been observed as stars in the days before their true nature was suspected, and they are naturally now missing from the places in which they were seen at the time. It is, of course, impossible to be sure that all the so-called " missing " stars are to be thus accounted for, but, in default of better evidence, it would be unsafe to assert that any real disappearance has been definitely proved. However, now that the whole sky has been photographed so as to record all the stars down to quite a low magnitude, astronomers in the future will be in a far better position to decide such questions than those who had only the older maps and catalogues to go upon.

But what of the second part of our question? Have we any record of the birth of a star? To this we can give a much more definite, if somewhat qualified, answer. We may say at once that there is no known example of a stellar body which has risen from invisibility to become visible to the naked eye, and *so remained*. So far as we know with any certainty, all the stars which we can discern now without a telescope have been so visible for at least two thousand years, and probably for much longer. On the other hand, there are numerous authentic records of the sudden appearance of bright star-like objects, which have remained visible to the naked eye for periods ranging from a few weeks to over a year, only to fade once more into complete obscurity. Such objects are referred to as "New" or "Temporary" stars, and in recent times have been more commonly described as *Novae*. Several are recorded as having appeared in the days before the telescope was invented, and of these we naturally know less than we do of those which have appeared since then. The one of which we have the fullest account was also one of the most remarkable, and is worthy of mention before we pass on to more recent appearances. This star blazed out with great suddenness in the constellation Cassiopeia in 1572. Like other bright novae, it was probably noticed by a large number of people almost simultaneously, but it is always associated with the name of Tycho on account of the thoroughness with which he studied it. In fact, he wrote a detailed monograph describing his observations, and this has come down to us. When Tycho first saw the star, on November 11, it was already brighter than Jupiter, but its light increased still further, so that it was within a day or two equal to that of Venus, causing the body to be visible to the naked eye in broad daylight. After this it faded gradually, passing through several changes of colour, and was lost to view after being visible altogether for seventeen months. It is impossible to say with certainty whether or not it still exists as a visible object. Tycho's rough instruments were not equal to the determination of its position with great accuracy. Two stars of about the twelfth magnitude are to be seen now near the place he deduced from his observations, and it may be that one of them is identical with the great nova, but we cannot be sure.

Another brilliant nova appeared in the year 1604 but from that time until 1901 no object of this

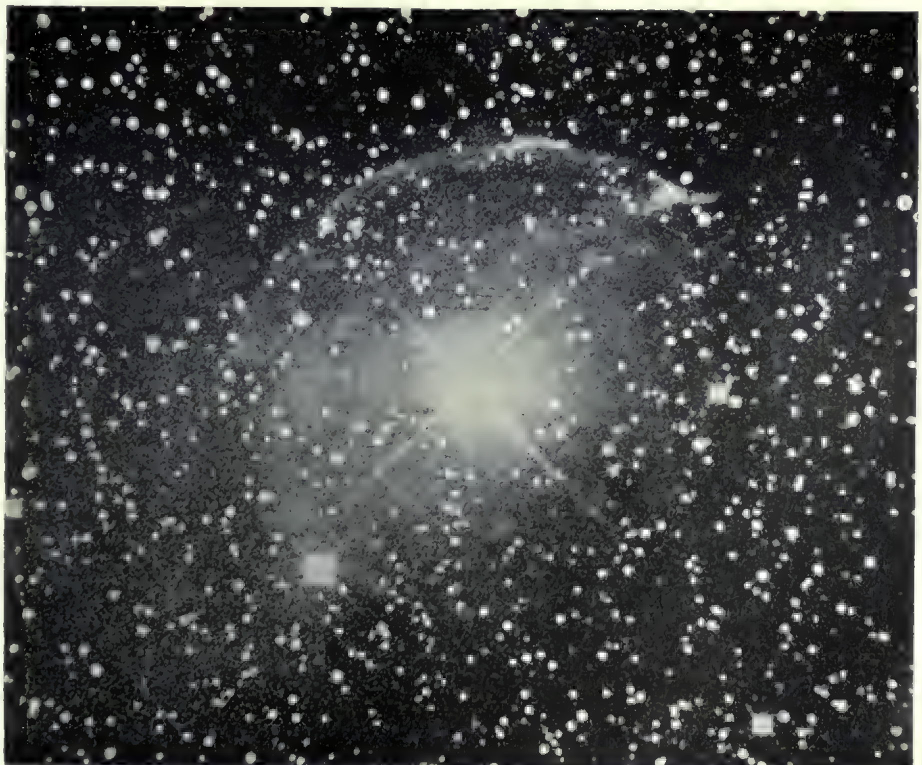


Photo by] [*G. W. Ritchey.*

NEBULOSITY SURROUNDING NOVA PERSEI, 1901, SEPTEMBER 20.

Several months after the outburst of Nova Persei, in February 1901, photographs of long exposure revealed the presence of a large faint nebula surrounding the star. It was soon found that the boundaries of this nebula were moving steadily outwards and at the same time becoming fainter. This motion of the nebula is best seen by noting the position, in this and the succeeding photograph, of the bright "horn" at the upper right-hand edge.

kind was seen to reach the first magnitude, though several fainter ones were observed. But already in the present century we have witnessed the appearance of two brilliant novae, each considerably brighter than the limit above mentioned. The first appeared in February 1901, in the constellation Perseus. At its maximum brightness it outshone Capella and Vega, and was for a short time the most brilliant star in the northern hemisphere. Thereafter it faded rapidly, and was lost to naked-eye vision after a few months. A still more splendid nova was seen in Aquila in 1918. It was first observed on June 8, when it was about as bright as Altair ; but by the following night it had become very much brighter, reaching magnitude – 1·0. It was thus inferior to Sirius alone of all the stars. Like Nova Persei, it soon began to fade, and was not visible without a telescope after the lapse of a few weeks. Several less conspicuous novae have been observed in the past eighty years, but space will not allow of a description of each. In all, forty-four objects of this kind have been recorded since 1572, though this number does not include certain very faint temporary stars lately found in some spiral nebulæ. Several of these forty-four were found on photographs at Harvard some time after their first outburst of light, so that it was too late to study their full life-history. However, many of the brighter ones attracted immediate attention from the earliest days of their visibility, and two or three have even been caught while still undergoing their rapid initial increase of light. A study of these has revealed a marked similarity in behaviour and general characteristics, so that a single description, with certain modifications in individual cases, will cover the facts so far observed with regard to these novae. It is true that we have as yet studied too few of these bodies to enable us to decide how far all or any of the following characteristics are invariable, but the frequency with which they have been observed points to the existence of some general law.

Photo by *G. W. Ritchey.*

NEBULOSITY SURROUNDING NOVA PERSEI, 1901, NOVEMBER 13.
This photograph, taken nearly two months after the first, shows the movement and fading of the nebulosity. It is now believed that we were observing, not the movement of matter, but the successive illumination of different parts of a dark nebula by the original outburst of the Nova. No other theory could account for the prodigious outward velocity indicated, having regard to the short interval and the demonstrably great distance of the star.

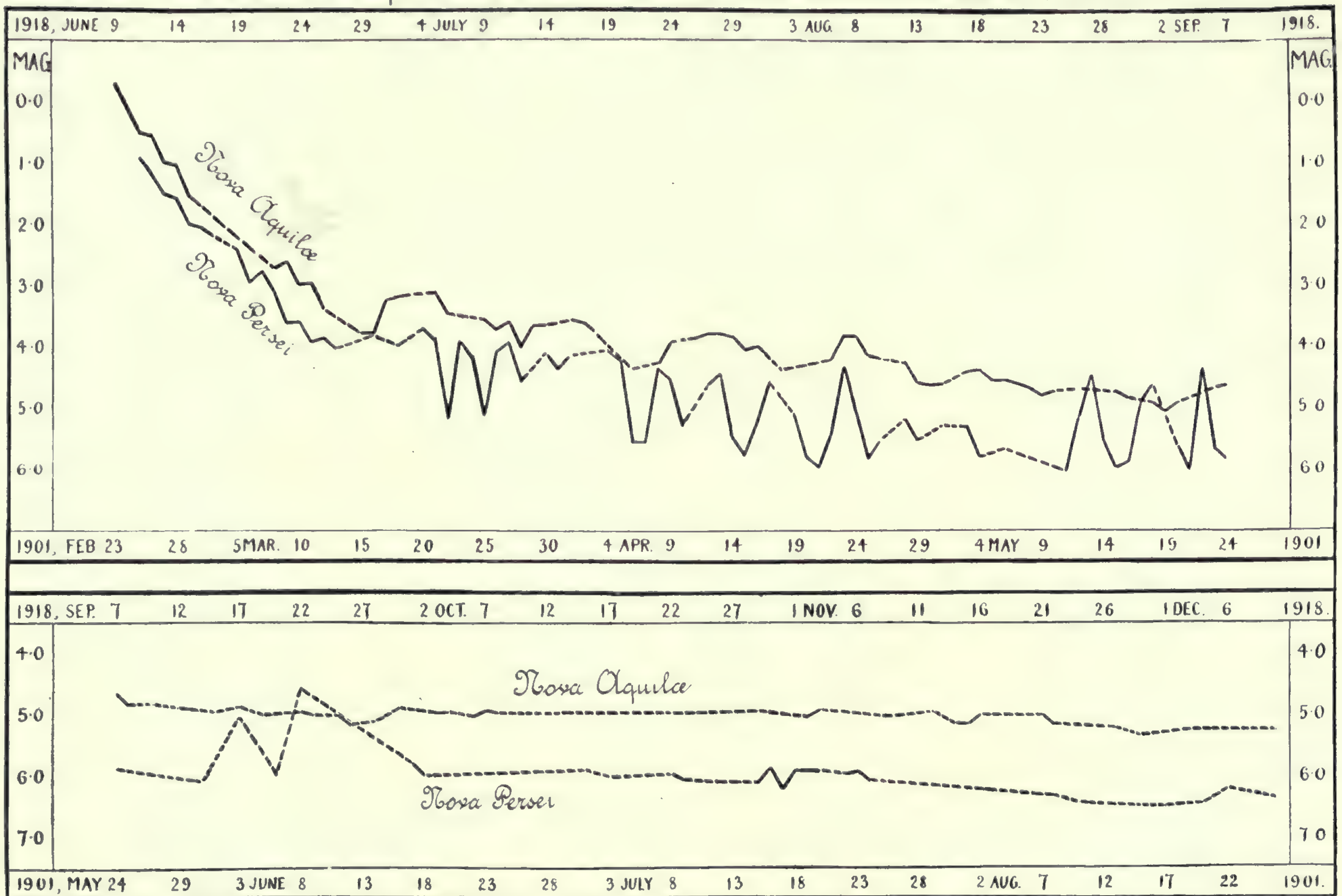
A distinguishing feature of the novae, and one of the earliest to be observed, is their striking distribution in the sky ; for, with one or two doubtful exceptions, they have all appeared in or very near the Milky Way. They seem also to have a tendency to be situated at the borders of comparatively dark spaces in this great structure, rather than in the midst of the brighter portions. The possible significance of this will be referred to later.

It is natural next to enquire whether the so-called novae are really "new" stars or merely temporary brightenings of bodies already existing in a fainter condition. In the case of the earlier novae,

A FIREBALL

The sudden appearance of a bright fireball, or "bolide," is among the most striking of celestial spectacles. Occasionally these bodies appear as members of definite showers of smaller meteors, but more often they burst upon our view unexpectedly and alone. Their light often equals and even exceeds that of the full moon, and for a short space they illuminate the whole landscape. Often they explode into separate fragments when at their brightest, and the sound thus created has been compared to the rumble of thunder or the discharge of a heavy gun.

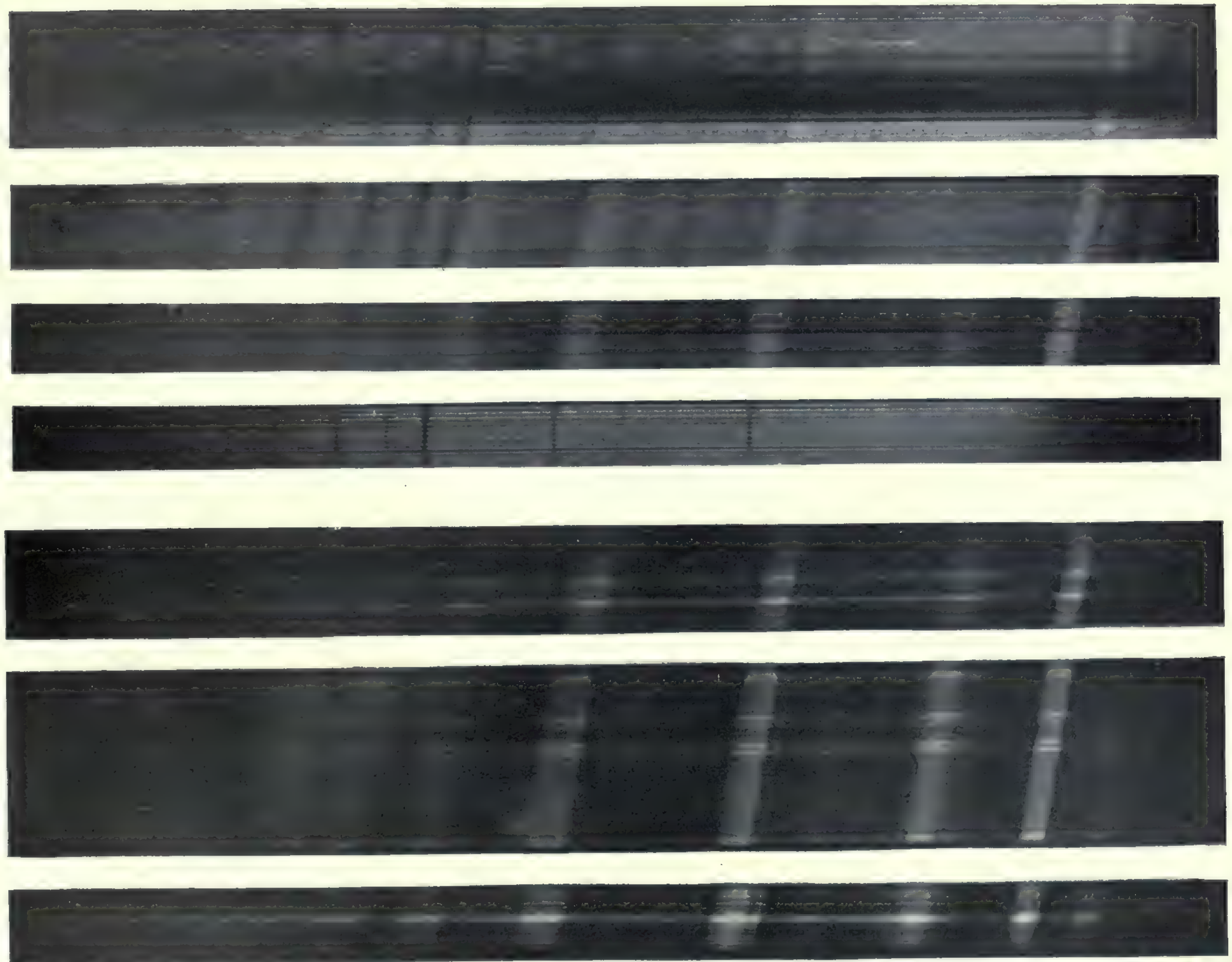
Radcliffe Magnitudes of Nova Aquilæ, 1918 and Nova Persei, 1901.



A. A. Rambaut] [M.N., R.A.S.

EARLY LIGHT-CURVES OF TWO NOVAE.

This diagram, constructed from observations made at the Radcliffe Observatory, Oxford, shows how very similar is the behaviour of bright novae in their earlier stages. The fall in luminosity is rapid at first, and but little interrupted. It then becomes more slow, with marked oscillations, which, however, tend to die out after two or three months. After this the fall is very slow and comparatively smooth.

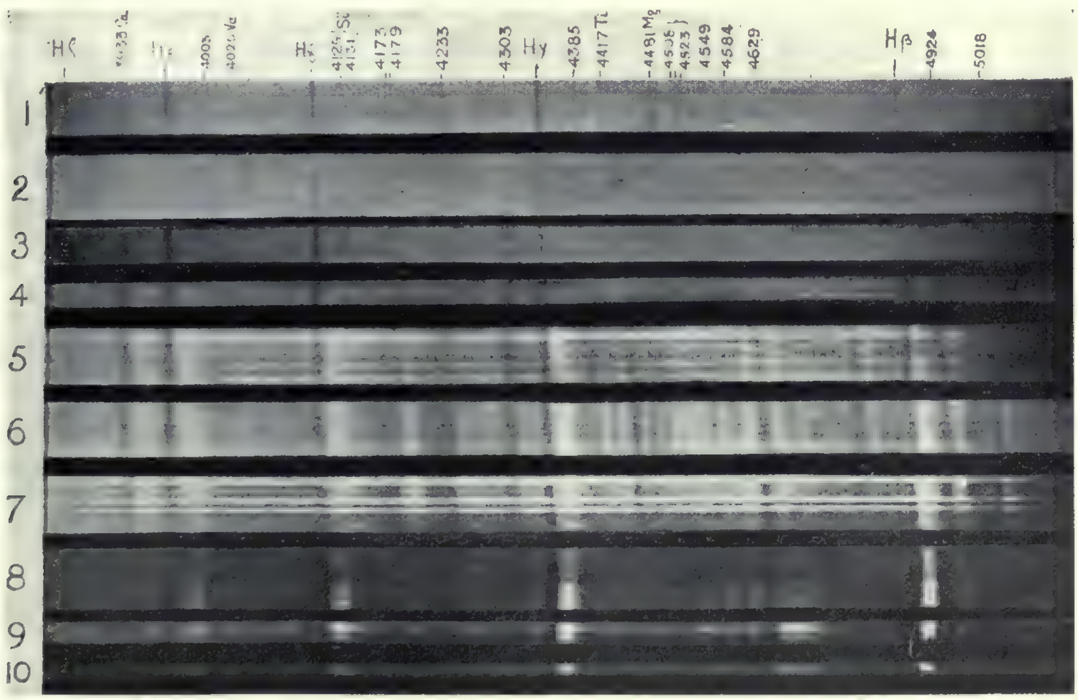


A. L. Cortie] [M.N., R.A.S.

PROGRESSIVE SPECTRA OF NOVA AQUILAE, 1918.

This Nova was at its brightest on June 9, and the spectra above cover the period between June 10 and July 29. The gradual fading out of the dark hydrogen lines and the increasing prominence of their broad bright companions will be noted. The topmost spectrum will be seen to be very similar to that of the tar Alpha Cygni, which is inserted for comparison in the middle of the series. The last two spectra show the gradual appearance, on the extreme right, of the bright nebular line (here a broad band) at wave-length 5007.

it is impossible to give a definite answer to this, since the heavens were then so poorly surveyed, especially with regard to the fainter stars. We can only say that none of these novae appeared exactly in the place of any recorded star. But we can speak with greater certainty with regard to more recent outbursts. The first nova to be identified with a known star was that which appeared in Corona Borealis in 1866. This object had previously been recorded as a faint star of magnitude 9·5 by Argelander, and is the only example of a nova previously recorded by visual means. It is, however, doubted by some whether it should be considered a typical nova at all. But in the case of novae that have appeared during the past thirty years, we can appeal to the valuable evidence of photography. During this period the whole sky, or at least the major portion of it, has been photographed again and again with instruments of various size, and it is only necessary to refer to these permanent and truthful records in order to ascertain whether any fresh nova corresponds in position with a star already photographed. The result of such comparisons as have hitherto been made has been to show



By permission of [*The Director of the Norman Lockyer Observatory.*

PROGRESSIVE SPECTRA OF NOVA CYGNI (1920).

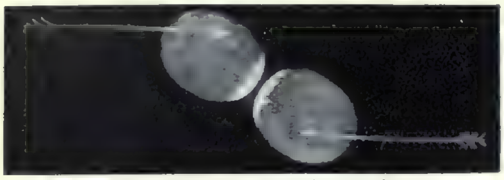
Spectrum No. 1 is that of Alpha Cygni. The remainder are of the Nova in order of development, the whole series covering an interval of about one month. No. 4 corresponds very nearly with the epoch of maximum brilliancy, and thereafter the marked development of the bright-line spectrum and the disappearance of the absorption (dark) lines is well brought out. The great width of the bright Hydrogen lines, dominating Spectrum No. 8, will be noted. This seems to indicate a shell of that gas rapidly expanding in all directions.

that in the cases of at least three bright novae—those in Perseus, Lacerta, and Aquila (1918)—faint stars have existed for many years in the exact positions occupied by them at the time of their outburst. In the remaining cases the failure to find any trace of a star may either mean that none was there, or that it was too faint to be recorded by the instrument and exposure employed in the earlier photographs.

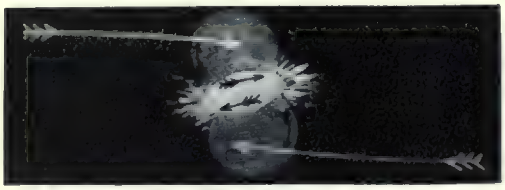
The behaviour of the novae that have been best observed may be summarised as follows. The great initial increase of light which draws our attention to them is exceedingly rapid and abrupt. The whole of it, amounting often to between ten and fourteen magnitudes, takes place within a space of less than a week, generally from two to five days. During this time the nova is pure white in colour and its spectrum is almost continuous. There are, however, a few faint dark lines in it, and these

increase in number and intensity up to about the time of maximum brilliancy, when the spectrum is of a modified A type, rarely found among ordinary stars, but exemplified by the case of α Cygni. Many of the dark lines are due to hydrogen, and they are greatly displaced towards the violet end of the spectrum. At this point the nova begins to fade pretty rapidly, and its colour becomes somewhat yellowish. The spectrum now contains a number of *bright* hydrogen lines, each of great breadth and scarcely at all displaced. That is to say, they lie on the red side of their dark companions, seen previously. Meanwhile the continuous background of the spectrum is fading, throwing the bright lines into greater prominence. Two or three days after maximum a fresh series of dark lines appears, still more displaced than the first, and the appearance of these is in turn followed by an increase in the intensity of the un-displaced bright lines. Soon after this the dark lines fade out, chiefly through the practical disappearance of the continuous spectrum, and the bright lines now dominate the spectrum. The colour of the nova has meanwhile become decidedly ruddy, owing to the great brilliance of the red line of hydrogen. Within two or three weeks of maximum there appears a fresh set of bright lines, and these are found to be identical with those observed in planetary nebulæ. As these grow in prominence the hydrogen lines slowly fade, and within a few months the spectrum is typically nebular in character. The nova has now lost its ruddy colour and appears greenish-white. Finally, the continuous spectrum partly reappears and the spectrum in this last stage is almost exactly that of a " Wolf-Rayet " star. By this time the nova, now sensibly white in colour, is only visible with a telescope, but it continues (now more slowly) to fade, until, after the lapse of five to ten years, it has reached a stationary condition as regards its mean brightness. The point thus reached appears to be almost exactly that from which the original rise took place, but in saying this we are only judging from the three objects that have been definitely recorded by photography in their " pre-nova " condition. During the early part of their fall most novae exhibit marked fluctuations of brightness of a semi-periodic character, but these tend to become less marked in the later stages. However, several novae—notably those in Perseus (1901), Ophiuchus (1848), and Cygnus (1876)—continue to vary in an apparently irregular manner, though their general fading has long ago ceased.

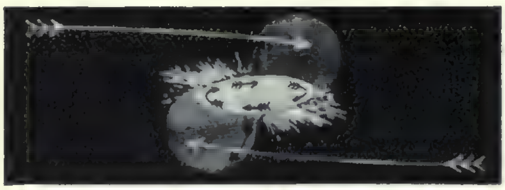
An explanation that will cover all the phenomena detailed above to the general satisfaction of astronomers is still lacking. Many theories have been put forward, each capable of explaining some of the observed facts, but leaving others unaccounted for. Upon one point there is general agreement.



Pair of Stars distorted and coming into impact.



Pair of Stars in impact.



Stars passing out of impact and formation of Third Body.

Showing entanglement of matter in each Body.

Two Variables and a Temporary Star.

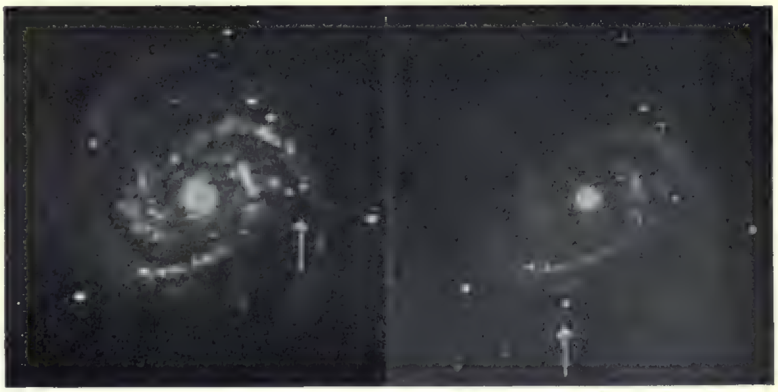
A. W. Bickerton] ["*Birth of Worlds and Systems.*"

BICKERTON'S " THIRD BODY " THEORY OF NOVAE.

Professor A. W. Bickerton believes that the appearance of a New Star is to be accounted for by the partial, or grazing, impact of two dark suns. The result would be the formation of a third body, composed of the grazing portions of the stars. The energy of motion of the latter would be largely converted into heat and the third body thus formed would be of an explosive, and therefore temporary, character. Such an explanation is consistent with many features of the nova spectrum.

The great suddenness and magnitude of the initial outburst, coupled with the spectroscopic evidence, makes it practically certain that we are witnessing an explosion of some sort. No other description could well apply to such a colossal and rapid release of energy. The difficulty lies in finding the probable cause of the explosion. The explanations suggested fall under two heads, according as they account for the explosion as spontaneous or as due to outside influences. As to the probability of a spontaneous explosion, very little can be said in the present condition of our knowledge. It has, however, recently been suggested that under certain conditions of temperature and pressure a star may gradually reach an unstable condition which would eventually lead to a sudden violent disruption. If such an event could be shown to be really probable on physical grounds, it would provide a very simple explanation, but at present it cannot be said to be much more than a vague conjecture.

The theories more commonly held have postulated some sort of celestial collision. This is in principle quite an ancient idea, but it is only within the past fifty years that pains have been taken to elaborate it in any detail. The two chief "collision" theories put forward are due respectively to Professors Bickerton and Seeliger. Each contemplates an entirely different type of collision. Bickerton believes that two dark stars (or a bright and a dark one) come into *grazing* impact, the result of which is the production of a third body composed of portions of each torn off during the graze. Such a body would undoubtedly be very hot and explosive, and might well exhibit the phenomena associated with a nova. Starting with this assumption, Professor Bickerton, whose theory was first published in 1879, was able to predict many features since observed in the spectra of novae, but it should be noted that the spectral changes, which he was the first to explain as due to a great explosion, do not by themselves prove what was its *cause*. It is upon this crucial point that astronomers have entertained serious doubts. These have been based principally on the relatively great frequency of novae as compared with the improbability of collisions occurring among stars so widely separated as those which we have been able to observe. We do not, of course, know how many dark, and therefore invisible, stars there may be, and this rather weakens the objection, but it is generally felt that the number would need to be improbably great to allow of so many collisions as seem to have been observed. To the writer it seems that a more serious objection is to be found in the return of at least three novae in a few years to a level of brightness exactly equal to that from which they rose in the first instance. It is difficult to see how this could happen to any of the bodies concerned in a violent stellar collision. Moreover, in the case of Nova Persei we have, in addition, the persistence of the same degree of irregular variability as was recorded photographically before its outburst. These facts would seem to suggest that the explosive process took place in some body other than that which, visible before, is still to be seen apparently unchanged. Possibly it may have had its origin in a body which made a close approach to the permanently visible star and thus suffered a disruption due to tidal effects.

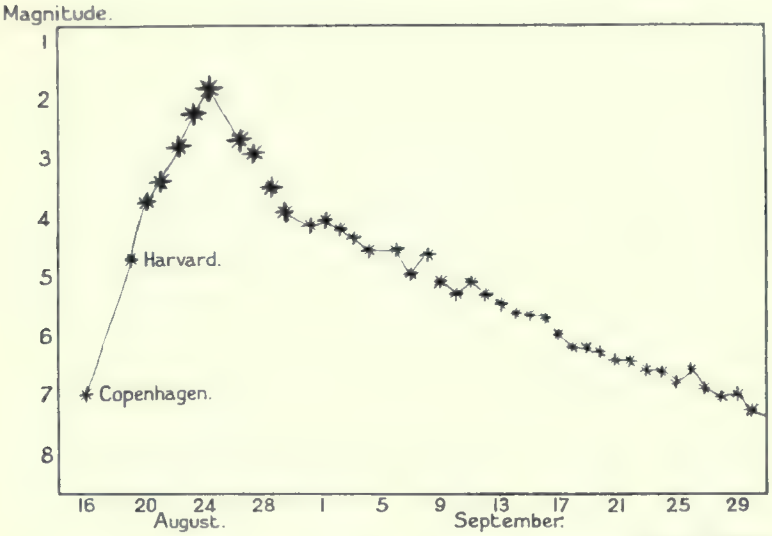


[*Adolfo Stahl Lectures.*

NOVAE IN A SPIRAL NEBULA.

In recent years many star-like objects of a temporary character have been found on photographs of certain spiral nebulæ. The assumption that these temporary "stars" are of the same order of real brightness as the Galactic Novae would indicate enormous distances and sizes for such nebulæ, and astronomers in general now tend to the opinion that the objects are not typical novae. The photographs above show two temporary objects that appeared in the same nebula at different times.

The theory of Seeliger is that a nova represents the effects of the passage of a star through a dark nebula, the phenomenon being somewhat analogous to the sudden rise in the temperature of a meteor on entering our atmosphere. If the resistance were great there would undoubtedly be an enormous



W. F. Denning.

EARLY LIGHT-CURVE OF NOVA CYGNI III (1920).

This Nova was first seen, by Mr. W. F. Denning, on August 20, when it had already risen to magnitude 3·5. At its maximum, four days later, it was a little brighter than the second magnitude. Subsequently, its image was found on photographs taken on August 16 and 19, at Copenhagen and Harvard respectively, but no earlier photographs record any star as bright as the fifteenth magnitude in the place of the Nova.

increase of temperature and pressure, such as might lead to the explosive effects observed. It has, however, been doubted whether the density of any nebula, bright or dark, could be high enough for the purpose. Moreover, it would need to have an unusually abrupt boundary to produce such a sudden reaction in the penetrating star. Another difficulty is the brevity of the whole process as compared with the enormous thickness of most nebulæ. This can only be explained if we assume that the nebula has a density sufficiently great to destroy the entire motion of the star within a few days, which seems improbable. On the other hand, we have good evidence that novae are in *some* way connected with nebulosity. To begin with, they are very apt to appear in those regions of the Milky Way occupied by dark obscuring clouds, and, as already mentioned, they are often seen near the edges of these. Then, in the case of Nova Persei, the blaze of the star actually lit up for a time a previously invisible nebula surrounding it. So we have good reason to believe that there is more than a chance connection between novae and nebulæ, and the case of η Argûs, in many ways so like a nova, lends additional weight to the supposition. It was at one time believed that novae were altogether exceptional phenomena, but the experience of the past thirty years has led us to moderate this view very considerably. From a statistical study of the discoveries of these bodies made by photography at Harvard, Bailey has recently concluded that one or two novae reach naked-eye visibility every year (though few are actually caught), and that at least nine attain the ninth magnitude in the same period. From this he goes on to conclude that in the course of a few million years there would be as many old novae in the sky as the present number of visible stars, and he suggests that every star which we now see has at some time or other been a nova. This is, perhaps, going too far. At any rate, it is difficult to see where, in the accepted course of a star's life-history, there can be room for such a stage. In this connection it may be mentioned that Lundmark has recently pointed out the probability that novae arise from both giants and dwarfs ; which makes it still more difficult to find their correct place in the scheme of things.

In recent years a number of temporary star-like objects have been photographed in several of the spiral nebulæ. It is somewhat doubtful whether they are to be looked upon as being comparable in size and type with the bodies just described. In any case, they are extremely faint, and the data available concerning them are necessarily meagre. We have little detailed knowledge of their light-curves and none whatever of their spectra. Their possible significance in relation to the distances and nature of spiral nebulæ is discussed elsewhere in this Work.

CHAPTER XVI.

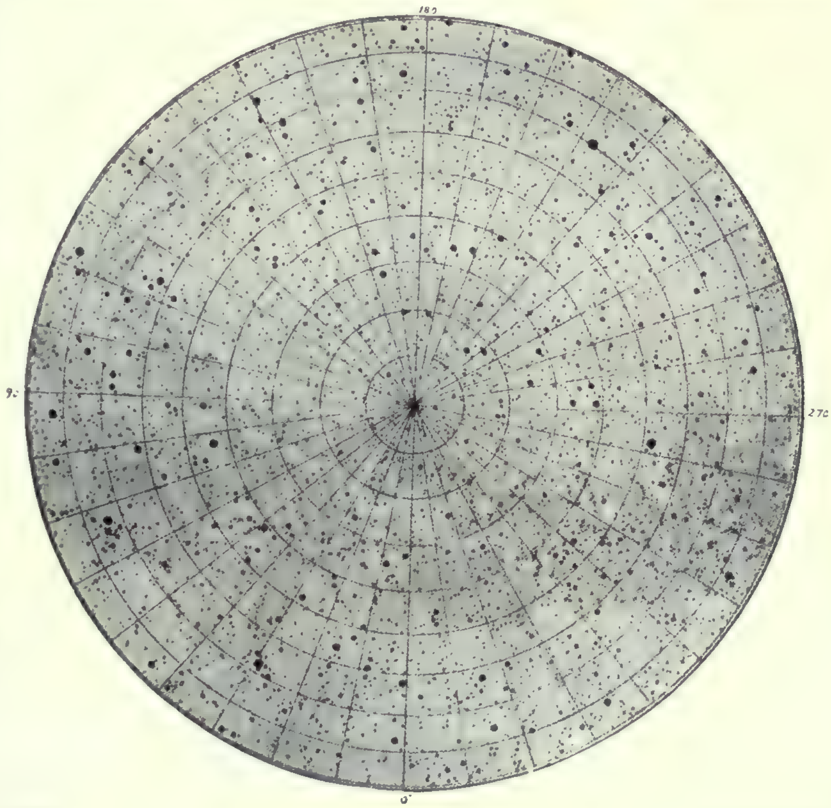
THE STRUCTURE OF THE UNIVERSE.

By Hector Macpherson, M.A., Ph.D., F.R.S.E., F.R.A.S.

"A KNOWLEDGE of the construction of the heavens," wrote Sir William Herschel in **1811**, "has always been the ultimate object of my observations." It may be truly said that to know the structure of the Universe is the ultimate object of modern astronomical research. How large is the stellar system ? What is its shape ? What is the place of our Sun in that system ? Are the Sun and stars in motion round some centre and in a certain plane ? How are the stars distributed ? These are some of the questions which must be answered before the problem of the Universe as a whole can be solved.

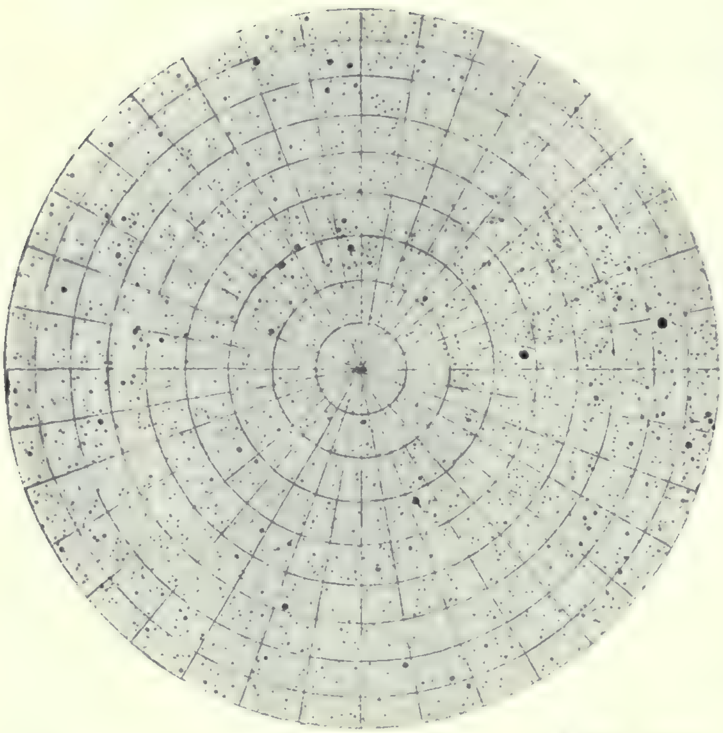
At first sight the problem appears to be well-nigh insoluble. When we lift our eyes to the heavens on a clear moonless night, we see an apparently innumerable multitude of stars of all degrees of brightness. In reality, however, only about three thousand, from the first to the sixth magnitude, can be seen by an observer possessed of average eyesight from any given locality on the Earth's surface. Even the casual observer is bound to notice that the stars are very unequal in brightness, and if he takes more than a passing look at the sky, he cannot fail to observe that the three thousand stars visible to the unaided eye are very unequally scattered. There are large spaces comparatively starless, such as the interior of the great square of Pegasus ; while there are regions of the heavens —the area covered by Orion, Taurus, and Gemini, for instance—where bright stars are numerous and faint stars are profusely scattered. Further, there are small regions where the stars are so closely crowded that they are designated as clusters. The more prominent of these, easily visible to the unaided eye, are the Pleiades and Praesepe.

The most prominent feature of the sky, however, is the Milky Way, or Galaxy ; a broad irregular belt of misty light which spans the heavens like a great arch. The Milky Way is to be seen all the year round, but is in north latitudes specially prominent in autumn, when it is almost perpendicular to the horizon. The galactic stream encircles the entire heavens, traversing the constellations Scorpio, Ophiuchus, Sagittarius,



From "*Visible Universe.*"

STARS VISIBLE TO THE UNAIDED EYE IN THE NORTHERN HEMISPHERE. This chart, constructed by the late Mr. J. E. Gore, indicates the positions and magnitudes of the stars visible to the naked eye north of the celestial equator. This, of course, does not include all the stars visible in Great Britain.



From] [*"Visible Universe."*

STARS VISIBLE TO THE UNAIDED EYE IN THE SOUTHERN HEMISPHERE.

This chart, constructed by the late Mr. J. E. Gore, gives the positions and magnitudes of the stars visible to the naked eye south of the celestial equator. The stream of the Milky Way is indicated on this and the preceding chart.

Aquila, Cygnus, Cepheus, Cassiopeia, Perseus, Auriga, Gemini, Monoceros, Canis Major, Crux, Ara, and Centaurus. It varies greatly in width and in brilliance. While bright in Cygnus and Aquila, it is, generally speaking, more brilliant in the southern skies than in the northern. The late Mr. Gore, a very careful observer of the Galaxy, maintained that "there is no portion of the Milky Way in the northern hemisphere at all comparable in brilliancy with the clouds of light in Sagittarius and Scorpio," and Colonel Markwick, another careful student, writes that "the Milky Way about the neighbourhood of Lupus, Ara, and Norma is a wonderful spectacle, full of a mysterious weirdness, with its delicate cloud-like wisps of light and dark passages twining in and out among the star mist. To my mind there is no part of the northern Milky Way to compare to this." Making due allowance for the fine atmospheric conditions in southern latitudes, there can be no doubt that the galactic stream is broader and brighter in the southern celestial hemisphere. It is by no means a uniform belt of light. For about a third of its extent, from Cygnus to Scorpio, it is divided into two parallel streams. Starless areas are not uncommon in the stream. The most prominent of these is the dark space known as the "coal-sack," in the vicinity of the southern constellations Crux and Centaurus. But there are many other vacancies and rifts, the most noticeable in northern latitudes being those in Cepheus and Cygnus.

The Galaxy has been familiar to observers since the dawn of astronomy, and was the subject of much speculation among the early thinkers, some of whom went very wide of the mark. Thus, Anaxagoras believed it to be the shadow of the Earth ; while Aristotle attributed it to atmospheric vapours. The Latin poet Ovid wrote of it : "When the sky is clear a path of very radiant white colour may be seen in the Empyrean. It is called the Milky Way and along it the immortals repair to the august dwelling place of the Lord of Thunder." To one penetrating Greek philosopher, Democritus, is due the credit of advancing the true theory, that the misty light is caused by the combined light of myriads of small stars, too faint to be separately visible. This happy guess—for it was nothing more—was abundantly confirmed when, in 1610, Galileo turned the newly-invented telescope to the Galaxy and resolved certain clouds of light into groups and clusters of faint stars. Even in a telescope of moderate size, the star-fields of the Galaxy can only be described as magnificent. Star upon star, serried ranks of stars in streams and clusters, blaze upon the vision of the observer. More powerful telescopes indicate still greater profusion and complexity while the revelations of the photographic plate are still more wonderful. Dr. Chapman and Mr. Melotte, in their description of the Franklin-Adams plates, remark that one particular plate covers "the Sagittarius region of the southern Milky Way, and the star-clouds on limited portions of it are so thick that in the case of

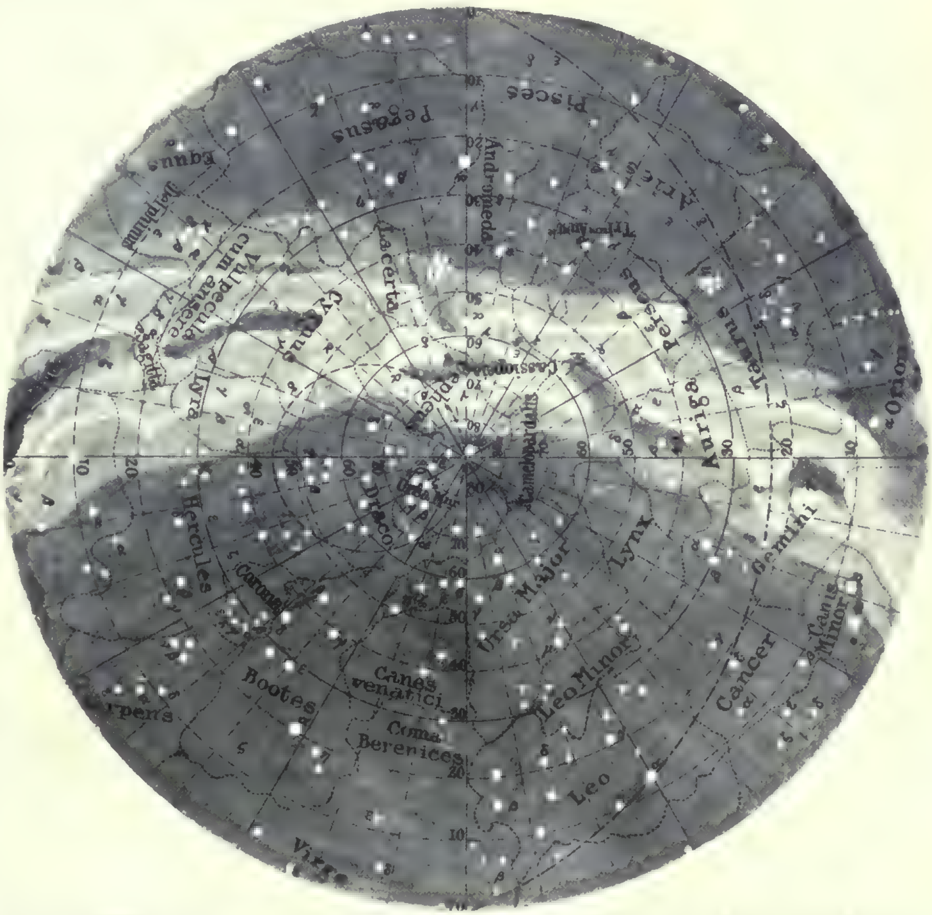
twelve out of the twenty-five areas counted on it, it was found impossible to count every star shown; the images of the faintest stars in these regions merged into one another, forming a continuous grey background. On every other plate of the Franklin-Adams series even the faintest star images shown were separate and distinct, and the counts included all stars visible. The extreme richness of the Sagittarius region may be judged of, then, when it is noticed that the incomplete counts on it show far more stars than are found in any other part of the Milky Way."

* * * * * * * * * * *

The Milky Way, then, is fundamental to the entire system of the stars. It is, as Professor Seeliger truly says, "no mere local phenomenon, but is closely connected with the entire constitution of our stellar system." The galactic plane is the fundamental reference-plane of the stellar system—the "ecliptic of the stars." The Galaxy is a great circle of the celestial sphere, which shows conclusively that the Sun is situated within it and not far from the plane.

There are three possible explanations of the Milky Way. Either it is (1) purely an optical appearance, due to the fact that the stellar system extends much farther into space along the plane than in the direction of the poles; or (2) it is an actual region of clustering where the stars are, relatively speaking, closely crowded together, in which case it is not a stratum, but a ring; or (3) it is due both to extension in space and to clustering.

The first of these explanations was advanced by Sir William Herschel at the beginning of his monumental work on the construction of the heavens. His hypothesis — the disc theory—had been, it is true, advocated in **1750**, by Wright, of Durham, an amateur astronomer of considerable insight; and also by Kant and Lambert. But it was put forward by these thinkers as a mere guess, unsupported by observational evidence. In **1784**, in his preliminary paper on the subject, Herschel indicated how the problem could be

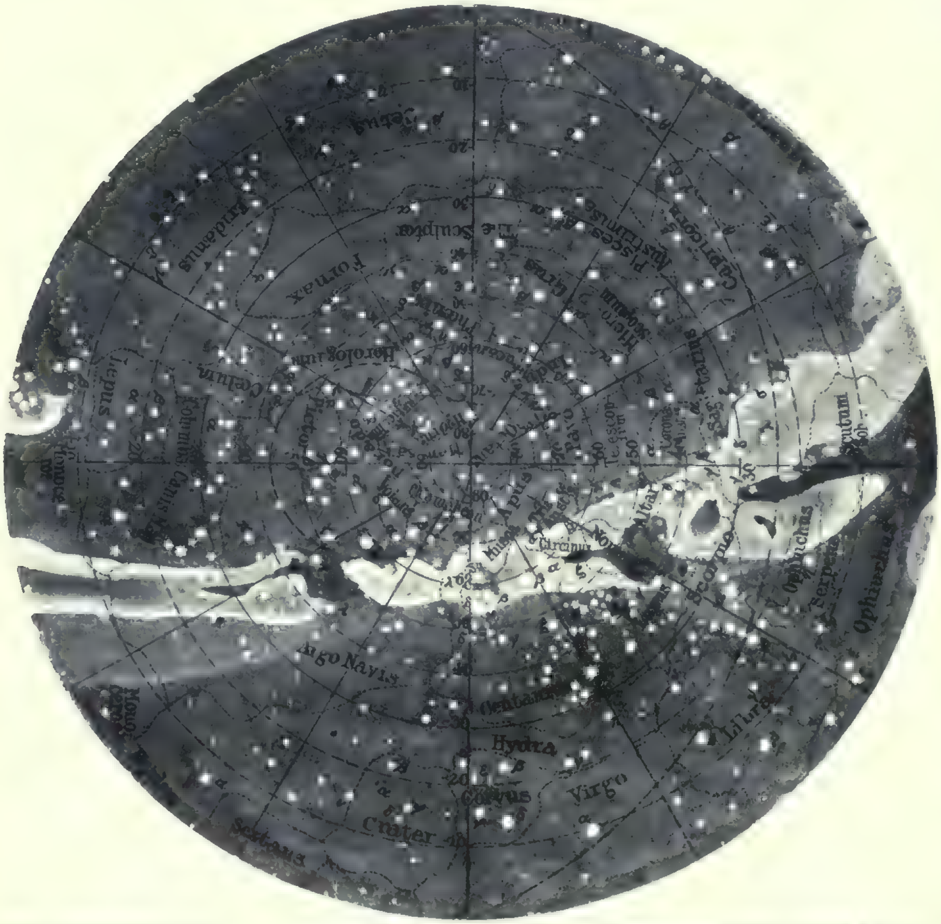


From "Astronomy for All"] [*By permission of Messrs. Cassell & Co., Ltd.*

THE NORTHERN MILKY WAY.

This diagram indicates the course of the Milky Way in the northern celestial hemisphere. The greater breadth and brightness of the stream in Cygnus and Aquila will be noticed. The depth of the stratum appears to be least in the direction of Auriga, Gemini and Monoceros. Hence the stream is narrower and less brilliant.

attacked on scientific principles. His work as a telescope-maker had greatly increased the space-penetrating power of this instrument and made possible his method of star-gauging. This method, to quote his own words, " consists in repeatedly taking the number of stars in ten fields of view of my reflector very near each other, and by adding their sums and cutting off one decimal on the right, a mean of the contents of the heavens, in all the parts which are thus gauged, is obtained." These gauges indicated remarkable differences in the star-density in various parts of the heavens. In the most crowded parts of the Milky Way Herschel occasionally counted as many as 588 stars in a field of view, while in other regions, removed from the galactic plane, he came upon practically starless spaces. He noted particularly the " remarkable purity or clearness in the heavens towards Leo, Virgo, and Coma Berenices on the one hand, and Cetus on the other." That Herschel in these regions undoubtedly penetrated to the confines of the stellar system was proved many years afterwards by Professor Celoria, the late director of the Brera Observatory, in Milan. In the course of his star-gauges at the north galactic pole Celoria found that with his small refractor, showing stars only down to the eleventh magnitude, he could see exactly the same number as could Herschel with his large reflector. This observation indicated that in this direction the limits of the galactic system had been reached. Otherwise Herschel's telescope would have shown many more stars than that of Celoria.



From "Astronomy for All". [*By permission of Messrs. Cassell & Co. Ltd.*

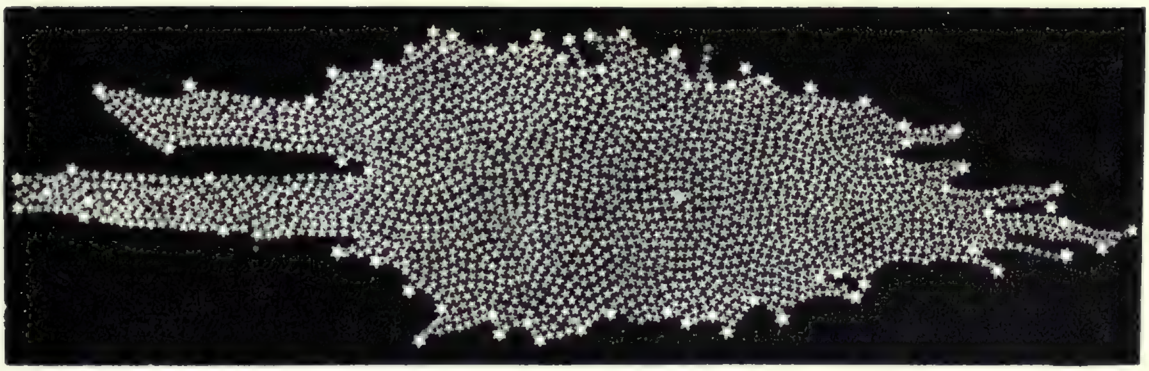
THE SOUTHERN MILKY WAY.

This diagram gives an idea of the irregularity of the light of the Milky Way, and the many rifts and vacant spaces which occur in the galactic stream. It is generally conceded that the Milky Way is more brilliant in the southern hemisphere than in the northern.

On the assumption that the stars were scattered throughout space with some approach to uniformity and that the gauging telescope was sufficiently powerful to penetrate to the limits of the stellar system, Herschel interpreted his observations to mean that the system extended to a much greater length along the plane than in the direction of the galactic poles ; and by means of his gauges he was enabled to outline the general shape of the system and to make a rough estimate of

the scale on which it was constructed. He sketched the system as a thin cloven disc of irregular outline, the cleft representing the division in the Milky Way stream from Cygnus to Scorpio. Herschel now proceeded to fix the position in the system of the Sun, which was viewed by him as a star of the Galaxy. The position assigned was near, but not quite at, the centre, slightly closer to the north galactic pole than to the south, and nearer to the boundary of the system in Aquila than to the boundary in Canis Minor. The stellar system was viewed as strictly limited in extent. "Our nebula," Herschel wrote, "is a very extensive branching compound congeries of many millions of stars."

The name "our nebula" was in itself suggestive. Herschel had been highly successful in resolving into stars the cloudy spots called "nebulæ" which the French astronomer Messier had catalogued in 1783. At this stage Herschel confidently believed that all nebulæ were clusters of stars at great distances in space, and that those which still defied his telescope would be resolved by more powerful instruments. These nebulæ he believed to be other Milky Ways; the terms "nebula" and "Milky Way" he treated as interchangeable, and he divided these nebulæ, or Milky Ways, into four classes or "forms," the forms differing in the degree of condensation or clustering. "We inhabit," he wrote, "the planet of a star belonging to a compound nebula of the third form." This nebula he viewed as strictly independent of the others—each system forming an island in space.

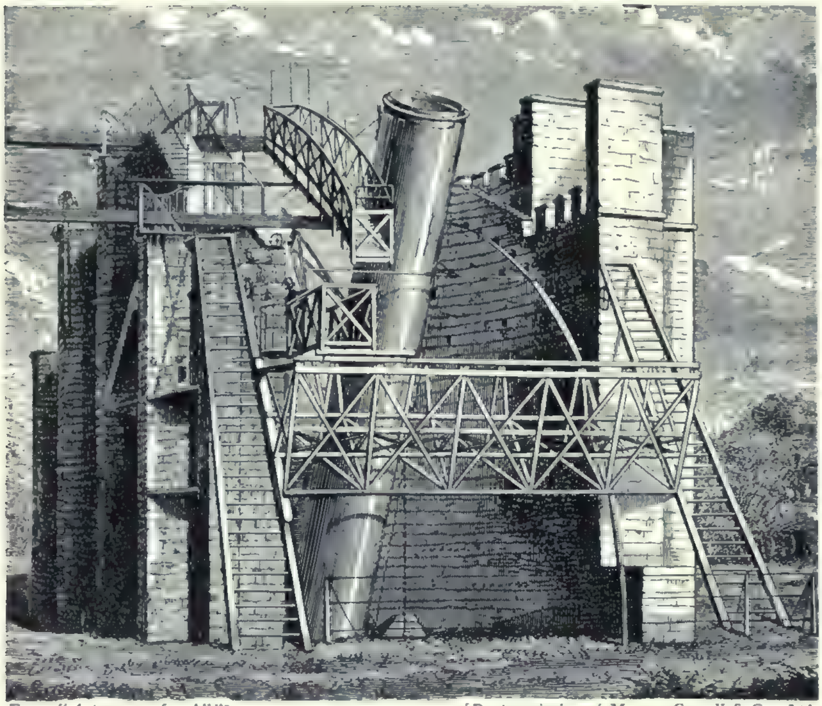


HERSCHEL'S DISC-THEORY.

Sir William Herschel in his earlier papers on the construction of the Universe, sketched the Stellar System as a thin flat disc. On this hypothesis, the phenomenon of the Milky Way is purely optical, due to the vast extension of the system along the plane. The position of the Sun, on Herschel's original view, is indicated by the large star to the right of the centre.

"It is true," he said, "that it would not be consistent confidently to affirm that we were on an island unless we had actually found ourselves everywhere bounded by the ocean, and therefore I will go no further than the gauges will authorise; but considering the little depth of the stratum in all those places which have been actually gauged, to which must be added all the intermediate parts that have been viewed and found to be much like the rest, there is but little room to expect a connection between our nebula and any of the neighbouring ones."

In the course of subsequent investigations, extending until 1818, Herschel was led to modify his views to a considerable extent. He had assumed that the stars were scattered with some approach to uniformity; but this was never more than an assumption. In 1785 he drew attention to what he called "two or three hundred gathering clusters" in our system, and he was led step by step to the view that the Galaxy was not a collection of myriads of "insulated stars" evenly scattered, but was rather an assemblage of clusters. "This immense starry aggregation," he wrote in 1802, "is by no means uniform. The stars of which it is composed are very unequally scattered and show evident marks of clustering together into many separate allotments." At the same time he had become convinced that many of the nebulæ were gaseous masses, and was thus led to give up his hypothesis of island universes. It has been maintained that he abandoned the disc-theory. In a certain sense he did. If by the disc-theory we mean the hypothesis that the stellar system is composed



From "Astronomy for All"] [By permission of Messrs. Cassell & Co., Ltd.

LORD ROSSE'S GREAT TELESCOPE.

The gigantic reflector which the third Earl of Rosse erected on his estate at Parsonstown, in Ireland, in 1845, was for many years one of the world's wonders. The diameter of the mirror is six feet. The usefulness of the telescope was much impaired by its location in the unfavourable climate of Ireland.

of myriads of evenly-distributed stars, then he may truly be said to have abandoned it. If by the disc-theory we mean, however, that the stellar system extends much farther in the direction of the plane of the Galaxy than in that of the galactic poles—that the stellar system is not globular, but more or less flat and disc-shaped—then Herschel cannot be said to have changed his opinion. His final conclusion indeed, was that the system was even more extended in the galactic plane than he had formerly believed. "The utmost stretch of the space-penetrating power of the twenty-foot telescope," he wrote in 1818, "could not fathom the profundity of the Milky Way." It may indeed be said that Herschel abandoned the first of the three possible theories of the Milky Way and, while not actually formulating a new hypothesis, inclined to the third alternative.

The second alternative—that the Galaxy is a ring of comparatively small stars encircling a stellar system of comparatively small dimensions—was not without able advocates in the latter part of the last century. The late Mr. R. A. Proctor, one of the most brilliant astronomers of his day, noticed that the brighter stars seemed to concentrate to the galactic plane as well as the fainter. In 1870 he plotted on a single chart all the stars—324,198 in number—contained in Argelander's *Durchmusterung* or survey of the heavens. This chart brought out not only the progressive increase of the faint stars towards the Galaxy; it indicated that, in Proctor's words, "in the very regions where the Herschelian gauges showed the minutest telescopic stars to be the most crowded, my chart of 324,198 stars shows the stars of the higher orders (down only to the eleventh magnitude) to be so crowded that by their mere aggregation within the mass they show the Milky Way with all its streams and clusterings." The elaborate star-counts of Gould, Schiaparelli, and Gore confirmed Proctor's result. Obviously, if the disc-theory as put forward by Herschel were true, the brighter stars should be, on the whole, evenly scattered. There are two possible explanations of this concentration of the brighter stars towards the galactic plane. Either the fainter stars of the Milky Way are intermingled with the brighter and are comparatively near—the phenomenon of the Milky Way being due to a comparatively thin ring of stars just outside the stellar system—or the brighter and nearer stars form a local cluster, flattened at the poles, whose plane is practically coincident with that of the Galaxy. As early as 1836 Sir John Herschel had been led to the first of these explanations. It was adopted by Proctor, by Gore, and other astronomers of weight. The late Miss Clerke, in 1905, defined the Milky Way as a "rifted and irregular ring marking the equator of a vast globe." Obviously, however, a serious objection to a thoroughgoing ring theory was the gradual increase in the

star-density with diminishing galactic latitude. If the Milky Way were actually a ring of stars surrounding a star-sphere, the average number of stars in any given region should increase not gradually but suddenly towards the boundary of the ring. This was brought out clearly by the elaborate study of stellar distribution made by Seeliger, based on the star-gauges of the two Herschels, the *Durchmusterung* of Argelander and Schönfeld, and the star-counts of Celoria.

These investigations show that stars down to the ninth magnitude are three times as numerous in the zone containing the galactic plane as in those containing the poles, while stars down to magnitude thirteen and a half have twenty times greater density of distribution. Seeliger's work convinced him that "the Milky Way is no mere local phenomenon," a conclusion fatal to the ring theory, at least in its simpler form.

The second explanation of the excess of the brighter stars in the galactic zone was adopted by the American astronomer Gould. He emphasised the fact that the bright stars are concentrated to a plane which does not quite coincide with that of the Galaxy, and he maintained that this "secondary galaxy" was due not to the intermingling of bright and faint stars but to the fact that "our own system forms part of a small cluster distinct from the vast organisation of that which forms the Milky Way and of flattened and somewhat bifid form." This hypothesis was not favourably received at the time of its promulgation, but it has been rehabilitated by recent research.

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The rate of progress in astronomy during the last twenty years has been quite unprecedented and in none of the sub-sciences into which the study is now divided has it been more rapid than in that relating to the structure of the Universe. Since the opening of the century various new methods of determining the distances of the stars have been devised and put into operation. In 1900 only about sixty stellar parallaxes were known with any degree of accuracy—all of these determined by the trigonometrical method. In the following year the late Professor Kapteyn, the famous Dutch

From] "Visible Universe."

POSITIONS OF THE SOLAR APEX ASSIGNED BY VARIOUS INVESTIGATORS.

The Solar Apex is the point in the sky towards which the motion of the Sun and Solar System is directed. Various investigators, using widely different data, have reached slightly different results. Considering the slender data on which Herschel worked, it is remarkable how near the truth was his first estimate in 1783.

astronomer, indicated the possibility of finding the mean parallaxes of groups of stars through the determination of their parallactic motion—the component of their proper motion due to the drift of the Sun. Dr. W. S. Adams, of Mount Wilson, discovered some years ago that the intensities of certain lines in stellar spectra depend on the absolute luminosities of the stars, and as a result he has been enabled to measure the absolute magnitudes, and hence the distances of hundreds of stars by means of the spectroscope. Professor H. N. Russell, too, has shown that in the case of eclipsing variable stars it is possible to derive their absolute magnitudes from a study of their orbits. The distances of ninety of these stars have been computed by Dr. Russell and Dr. Shapley, and two-thirds of them are more distant than a thousand light-years, while a number are over five thousand light-years away. An even more valuable method of measuring the scale of the stellar system is that which depends on the Cepheid variables. An American lady astronomer, the late Miss Leavitt, of Harvard College Observatory, discovered some years ago that for twenty-five Cepheid variable stars in the smaller Magellanic Cloud, the length of period depends on the apparent brightness. As all the variables in the Cloud are at practically the same distance from the Earth, the correlation is actually between the intrinsic brightness and the period. As soon as observers have ascertained the period and apparent magnitude the absolute magnitude of a Cepheid may be at once deduced and the distance computed. Still another important method has been devised by Dr. Russell and others for ascertaining the minimum distance of the bright helium stars of Class B in the Harvard sequence of stellar spectra. According to Russell's theory of stellar evolution, which appears to be

JOHN ELLARD GORE (1845–1910).
One of the most distinguished students of the distribution of the stars and the structure of the Universe. He was a non-professional astronomer, with very slender instrumental equipment. His chief conclusions were summed up in his work, "Our Visible Universe." He was an Irishman, and by profession a civil engineer.

M. CAMILLE FLAMMARION.
This veteran French astronomer was born in 1842, and was a mere boy when he began the study of astronomy. He has for years directed the Flammarion Observatory at Juvisy, near Paris. One of his chief discoveries was that of common proper motion of widely separated stars.

firmly established, only stars of large mass are able to attain to the unusually high temperatures of B-stars. Hence a B-star, however faint it may appear, must have a certain minimum absolute magnitude. It is true that the spectra of the very faint stars cannot be observed, but it has become possible in recent years to ascertain the hypothetical spectra of the faint stars. As is well known, the photographic plate is considerably more sensitive than the eye to certain wave-lengths of light; the difference between the photographic and visual magnitude of a star is therefore due to the star's colour, and is called the "colour-index." The colour-index having been ascertained, the approximate spectral type can be determined of very faint stars whose spectra cannot be directly observed.

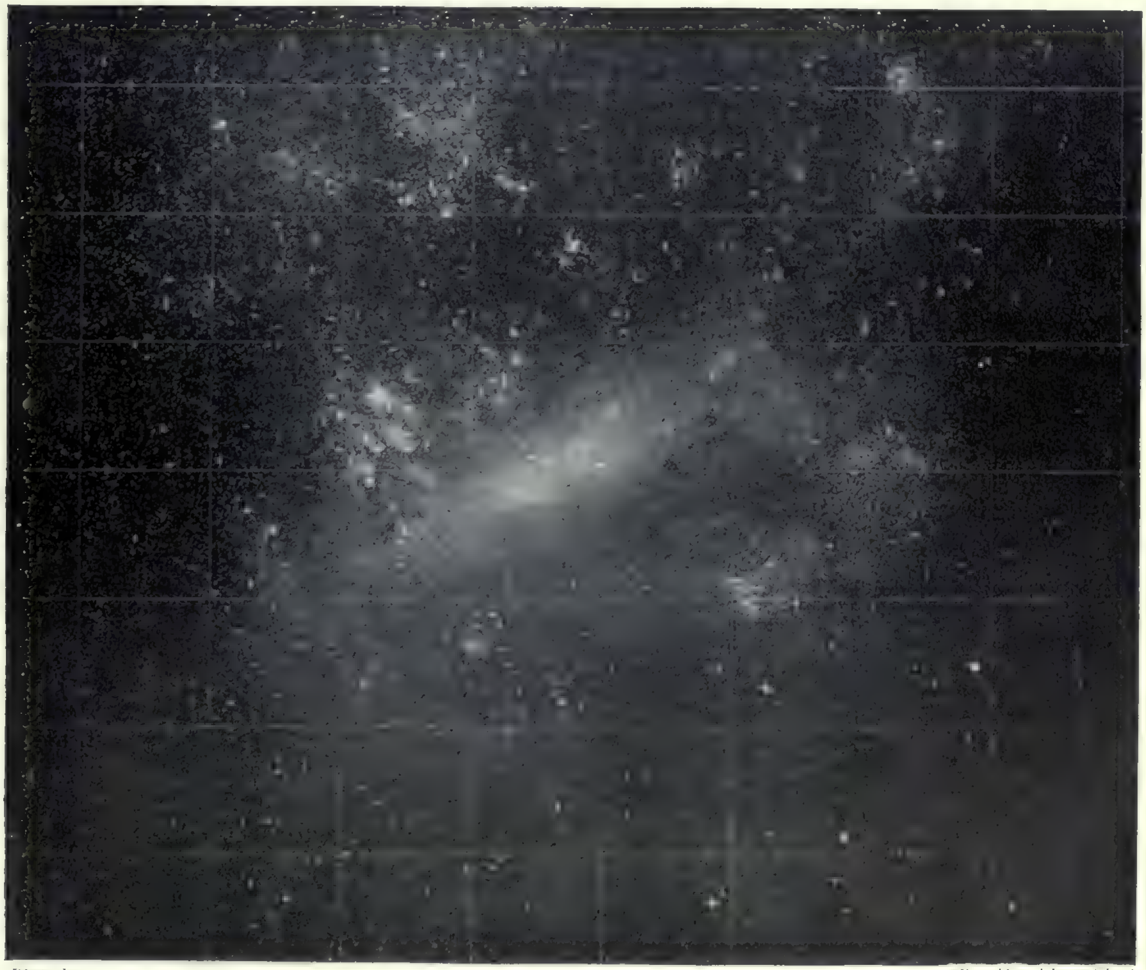


Photo by *Franklin-Adams Chart.*

THE NUBECULA MAJOR,

or Greater Magellanic Cloud, is one of the most striking objects in the southern celestial hemisphere. It is situated at a considerable distance from the galactic plane and appears to be a semi-dependent satellite system. Dr. Shapley has recently computed its distance as 110,000 light-years, and its diameter as 15,000 light-years.

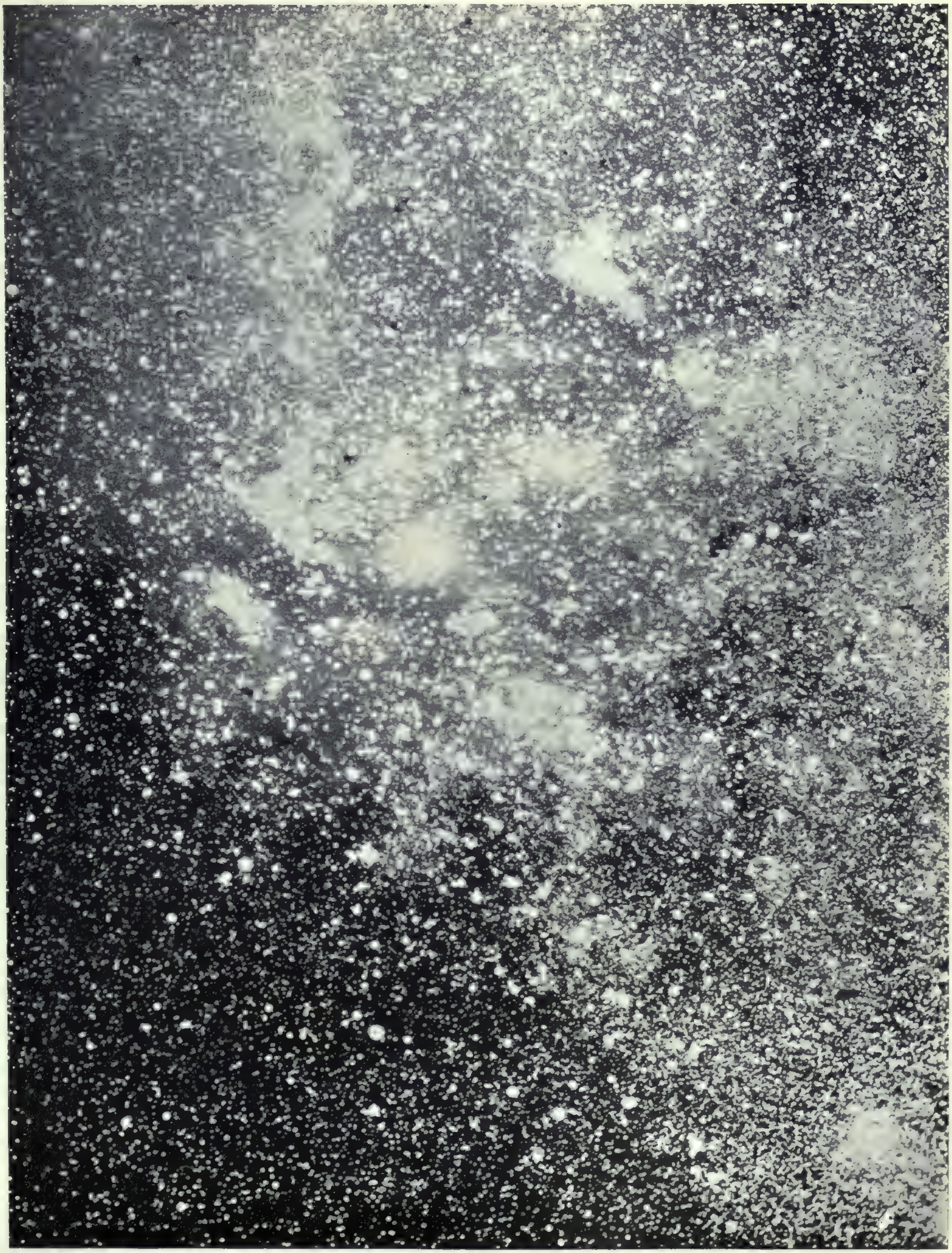
The application of these methods has resulted in a remarkable advance towards the solution of the problem of the structure of the Universe. In 1916 a highly important investigation was completed by Professor Charlier, of Lund, the distinguished Swedish astronomer. In his paper on "The Galaxy of the B type Stars," Professor Charlier made the fairly safe assumption that stars of this particular type do not differ very much from one another in absolute magnitude. On the basis of this assumption, he was in a position to throw out a sounding-line, as it were, far into space, and to determine the distances of the B-stars brighter than the fifth magnitude. He found that these stars

form a well-defined flattened cluster, whose plane is very similar to that of the Galaxy, with its centre of gravity in the constellation Carina. Charlier found that the farthest limits of the cluster were at a distance of about 2,000 light-years from the Sun. He assumed that he was taking soundings of the depth of the stellar system. "We are," he said, "in a position to get, with the help of the B-stars, what might appropriately be called a skeleton image of the Milky Way." This supposition was not out of harmony with the current estimates of the diameter of the stellar system, which ranged from about 7,000 to 18,000 light-years.

In 1914 Dr. Harlow Shapley, now director of the Harvard College Observatory, commenced with the aid of the 60-inch reflector of the Mount Wilson Observatory in California, his "Studies based on the colours and magnitudes in Stellar Clusters." The clusters investigated were of two distinct classes—the compact globular clusters in high galactic latitudes removed from the plane of the Milky Way, and the open galactic clusters which appear to be simply condensations of the stars of the Milky Way. Obviously the measurement of the distances of clusters of the latter type is of great importance in fixing the minimum distance of the clouds of faint stars. In the galactic star-clouds in the vicinity of the open cluster Messier 11 Dr. Shapley discovered faint stars with negative colour indices—that is to say, faint blue stars of B type. "The cluster stars," he wrote in April 1917, "are probably giants in luminosity . . . and accordingly the distance of the group must be of the order of 15,000 light-years," and he pointed out the significant fact that "if these stars are typical in absolute brightness, the size of the galactic system in the plane of the Milky Way is many times greater than has been computed from studies of variables and investigations of the motion and magnitudes of the brighter stars."

PROFESSOR GIOVANNI CELORIA (1842–1920).
This distinguished Italian astronomer was for many years assistant to the more famous Schiaparelli, whom he succeeded in 1900 as director of the Milan Observatory. His chief work was on the distribution of the stars and the structure of the Universe.

Dr. Shapley's exhaustive study of the distances and positions in space of the globular clusters has enabled him to ascertain the approximate extent and shape of the stellar Universe. Several independent methods of measurements were used in determining these distances, and on the whole these methods are mutually confirmatory. "The presence in some clusters," says Dr. Shapley, "of Cepheid variables of known period and brightness permits accurate measurement of distance, thanks to the valuable characteristic behaviour of Cepheid stars. Correlation of the brightness of the variables with the brightness of other stars that are always present in globular clusters extends the method ; and, for the clusters whose variable stars have been studied, the correlation of distance with apparent diameter and with total brightness yields simple means of estimating the distances of all globular clusters prior to knowledge of the variability of their stars." By means of these various methods, Dr. Shapley fixed the positions in space of eighty-six globular clusters. He defines these as "cosmic units," sub-systems dependent on the greater galactic system. The nearest of these, Omega Centauri, is 20,000 light-years distant from the Solar System, and the most distant—N.G.C.7006—is so far off that light requires 220,000 years to travel to the Earth. The globular clusters appear to form a great ellipsoidal system, divided by the



From "Knowledge." | | *Photo by Professor Max Wolf.*

NEBULOSITIES IN CYGNUS.

Cygnus is one of the most striking constellations in the heavens. Here the Galaxy becomes brighter and broader, and at the same time the stream becomes more irregular. In Cygnus occurs the "great bifurcation," or division of the Milky Way into two separate streams. There is much nebulous matter in this constellation. Much of it is dark and not easily discerned, but there are also many bright nebulosities. It has been shown recently by Dr. Hubble that these bright nebulæ either shine by reflected starlight or are excited to luminosity by the radiation of the stars involved in them.

From "Knowledge." *Photo by Professor Max Wolf.*

REGION OF THE MILKY WAY IN AQUILA.

Aquila is a galactic constellation, and presents some very fine fields of view to the observer. Its brightest star, Altair, is one of our nearer neighbours, seventeen light-years distant. This photograph represents a dense stellar cloud.

plane of the Galaxy—forty-three clusters being on either side. The stellar system proper is of the same diameter as this system of globular clusters—about 300,000 light-years. The centre of gravity of the latter system is therefore the centre of gravity of the former. It is situated in the direction of the constellation Sagittarius amid the dense star-clouds of that region, about 60,000 light-years from the Sun. Our Sun, then, is not near the centre of the stellar system as was formerly believed. We look through a much greater extent of space and see a vastly greater number of stars in the direction of Sagittarius than in that of Auriga ; hence the great brilliancy of the southern Milky Way.

In the main, modern research confirms Herschel's theories of the Galaxy, while emphasising the existence of many clusters in the stellar system. Thus the third alternative theory would seem to be the true one. " The phenomenon of the Milky Way," says Shapley, " is largely an optical one. Although the existence of local and occasionally very extensive condensations of Milky Way stars is not denied, the conception of a narrow encircling ring is abandoned." The stellar system is thus shown to be a thin disc proportionally almost as flattened as the Solar System itself. " A thin central stratum of the galactic segment contains every star that has been seen and has been photographed for our catalogues. This stratum of stars apparently deviates less than two thousand light-years from the galactic plane." In other words, the thickness of the stellar system is about one-sixtieth of its diameter.

This vast system contains an almost inconceivable number of stars. It has been computed from reliable data that the total number of stars in the stellar system lies between one and two thousand millions. This is exclusive of dark stars, of the existence of which there is evidence, and of the stars in globular clusters. The figure is staggering to the mind, but it is strictly finite. These stars are divided into the two classes of Giants and Dwarfs, and members of these classes seem to be freely intermingled. The Dwarfs would appear to outnumber the Giants. Among the twenty-one nearest stellar neighbours of our Sun, only five exceed the Sun in luminosity.

The stellar system, so far from consisting of stars scattered with an approach to uniformity, would appear to be made up of a great number of clusters of stars. The researches of Dr. Shapley indicate that the Sun is a member of a subordinate cluster. The existence of such a cluster, as already remarked, was maintained by Gould, but his views did not meet with general acceptance. This cluster is identical with Professor Charlier's system of the B type Stars, which he believed to be identical with the galactic system. For the fact that the plane of the local cluster is slightly inclined to that of the stellar system we have as explanation the existence of the so-called " secondary

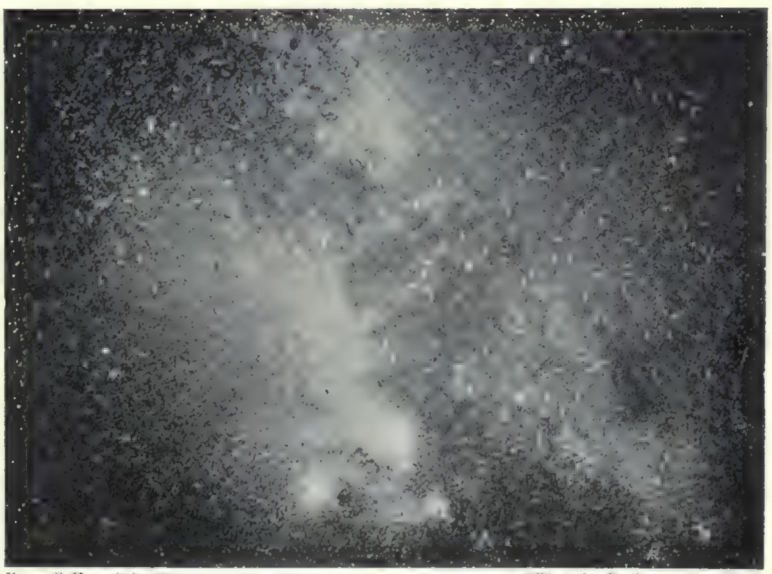
galaxy "—the belt of brilliant stars which includes Taurus, Orion, Canis Major, and other bright constellations. Dr. Shapley points out that not only the very bright stars of types B and A in this region are to be classed as members of the cluster, but also the belt of stars of magnitudes from three to seven.

It has long been known that several classes of stars are strongly concentrated towards the galactic circle and also, as we now know, to the plane of the local cluster. Thus, the late Professor E. C. Pickering showed many years ago that while the stars of Secchi's second and third type appeared to be disturbed more or less uniformly, the first-type stars were more or less concentrated to the galactic plane. The concentration is most clearly marked in the case of the sub-class known as the B-stars on the Harvard classification. Not only the B-stars but the rare stars of type N and the relatively uncommon Wolf-Rayet stars are strongly condensed to the plane. Of ninety-one Wolf-Rayet stars, seventy are actually within the borders of the Milky Way, while twenty-one are in the outlying clusters, the Magellanic Clouds. In addition, two kinds of variable stars -Cepheid and eclipsing variables—show the same condensation. The gaseous nebulæ, too—both irregular and planetary—obey the same law of distribution. Dr. Hubble, of the Mount Wilson Observatory, finds distinct evidence of a double concentration in the case of the irregular nebulæ—towards the Milky Way itself and towards the plane of the local cluster. The meaning of this fact evidently is that some of these nebulæ are situated within the local cluster and others far beyond, in the Milky Way clouds.

Recent research has shown that bright nebulæ are but particular cases of dark. Many of the dark rifts and spaces in the Milky Way now find their explanation not in the total absence of stars from these regions, but in the existence of vast masses of dark nebulous matter which acts as a veil cutting off the light of the stars beyond. In the early years of the century Dr. Max Wolf photographed a nebula in the galactic constellation of Cygnus which he noticed to be placed centrally in a very fine lacuna devoid of faint stars, surrounding the luminous cloud like a trench. The most striking fact regarding this object is that the starless space encircling the nebula forms the end of a long channel. Dr. Wolf threw out the hint that this starless space was due to a dark mass absorbing the light of the fainter stars. As a result of his long-continued photographic study of the Milky Way, the late Professor Barnard became convinced of the existence of this dark nebulous matter and in 1919 he published a list of 182 of these dark masses. Much of the irregularity of star-distribution in the Milky Way, therefore—irregularity which is apparent to the unaided eye—is due not to lack of stars but to the presence of these great dark masses, almost stationary in space, which appear to be the primæval chaos from which suns and worlds are born.

* * * *

In the unravelling of the tangled skein of stellar motions remarkable success has attended the labours of astronomers. Only two hundred years have



From "Knowledge." *Photo by Professor Max Wolf.*

REGION IN SAGITTA.

The small constellation Sagitta is situated between Cygnus and Aquila. It contains no star brighter than the fourth magnitude, but is rich in star-fields. It is situated in the stream of the Milky Way.

PROFESSOR J. C. KAPTEYN (1851–1922).
Jacobus Cornelius Kapteyn was one of the greatest astronomers of his time. From 1878 to 1921 he was Professor of Astronomy at Groningen, in Holland. His most outstanding discovery was that of the two star-streams.

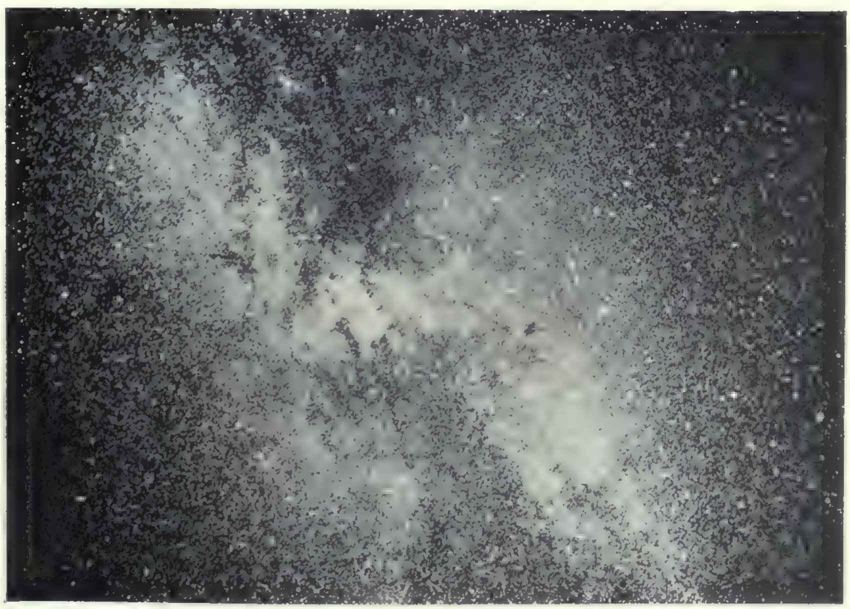
elapsed since Halley showed the name "fixed stars" to be a misnomer. In 1718 he announced that four of the bright stars, Sirius, Arcturus, Aldebaran, and Betelgeuse had perceptibly altered their positions on the celestial sphere since the time of Ptolemy. By 1756 Tobias Mayer, of Göttingen, was able to draw up a list of fifty-seven stars with perceptible proper motion. The elder Herschel, maintaining that "there is not in strictness of speaking one fixed star in the heavens," essayed in 1783 to determine the proper motion of our own particular star, the Sun. Obviously, the motion of the Sun can be detected only through the apparent motion or drift imparted to the stars; just as the orbital motion of the Earth is reflected in the apparent irregularities of the movements of the planets. If the Sun is moving in a certain direction, the stars in front will appear to disperse while those behind will appear to draw nearer together. Were the stars stationary and only the Sun moving, the problem of determining the solar motion would be a very simple one; but it is rendered highly complex by the motions of the individual stars. It is necessary, therefore, to decompose the proper motions of the stars into two components, one representing the real movements of the individual stars and the other, which is called the "parallactic" motion, resulting from the translation of the Sun and planets. Herschel dealt with the proper motions of seven bright stars, and separating what he believed to be the apparent from the real components, he concluded that the Sun, carrying with it the planets and their satellites and the cometary bodies, was moving towards a point in the constellation Hercules, with a velocity not less than that of the Earth in its orbit.

The fact of stellar motion being admitted, the question naturally arises whether these motions are systematic and whether the stars form a system in the sense in which the planets do? Is there a central body round which the stars are revolving, which holds a place in the stellar universe analogous to that of the Sun in the planetary system? In the middle of the last century Mädler, the distinguished German astronomer, attempted to use the proper motions available to him for a frontal attack on the problem of the orbits of the stars. Making the reasonable assumption that the mutual attractions of the different stars would cause the bodies at the confines of the system to move more rapidly than at the centre, he sought the centre of gravity in a region of sluggish proper motions. All stars nearer than the Sun to the centre of the system must lag behind the Sun because of their slower motion. So Mädler concluded that if community of motion in a direction opposite to that of the Sun be found in any part of the heavens, it might be reasonably assumed that the centre of gravity lay in that region. He found in the constellation Taurus a common proper motion, small in amount, and he fixed on Alcyone, the chief star of the Pleiades, as the central sun, or more correctly, as the body occupying the centre of gravity of the stellar system. Struve's verdict, "much too hazardous," has been unanimously endorsed by astronomers. What Mädler actually discovered was not the motion of the stars round the Pleiades, but the existence of a common proper motion among the stars of the constellation Taurus.

The significance of this discovery was not realised, however, until later in the century, when instances were found of two or more stars sharing a common proper motion. Thus Flammarion discovered that the proper motion of the bright first-magnitude star Regulus was the same in amount and direction as that of a faint star of the eighth magnitude known as Lalande 19,749. Other instances of community of motion were also noted by Flammarion in the course of his investigations. A more striking instance of this " star-drift " was discovered by Proctor in 1870. This is the common proper motion of five of the seven bright stars forming the familiar group known as " The Plough," in Ursa Major. Proctor mapped the proper motion of these seven stars and noticed that five with the two small stars attached to one of them—Mizar—were moving at the same rate in the same direction ; and he computed that the odds were half a million to one against the occurrence being accidental. Some years later, the velocities of these stars in the line of sight were measured by Huggins by means of the spectroscope, and his observations were confirmatory of Proctor's conclusions. Many years afterwards, in 1909, Dr. Hertzsprung, of Potsdam, pointed out that eight other prominent stars, one of which is Sirius, are moving along paths parallel to those of the five stars of the Plough.

Recent research has shown the true meaning of the community of proper motion among the stars in the constellation Taurus, which Mädler first detected. These stars form a moving cluster, a vast assemblage of suns travelling together through space with the same velocity and in the same direction. There are thirty-nine bright stars known with certainty to belong to this group. According to Professor Eddington, five of these are of fifty to one hundred times greater luminosity than the Sun, and thirty-four of from five to fifty times ; and there can be no doubt that many additional fainter stars in the region also belong to the cluster, but until further determinations of their motion have been made, these cannot be picked out with certainty. The whole cluster appears to be more or less globular in form with a slight condensation at the centre. Another example of a moving cluster is to be found in the constellation Perseus, first pointed out by Professors Kapteyn, Boss, and Eddington. All the stars of a certain special type—type B in the Harvard sequence—in this region have a common proper motion. A still larger moving cluster is formed by the bright stars of the constellation Orion, with the exception of Betelgeuse, but in this case, as Professor Eddington remarks, " it is just possible that the associated stars may be dispersing rather rapidly."

The existence of moving clusters and associated groups of stars indicates that the motions of the stars are not at random. Conclusive proof of this is afforded by a still more significant fact, which came to light in the course of investigations



From " Knowledge."] *Photo by Professor Max Wolf.*

REGION OF THE MILKY WAY IN CYGNUS.

Cygnus is particularly rich in galactic star-fields, and this photograph represents a typical region. Each of the tiny specks represented on this photograph is a Sun, and many of these are giant stars.

on the solar motion. In 1895 the German astronomer Kobold, discussing the fact that different positions had been assigned to the apex of the solar motion—the point towards which the Sun is moving—by different investigators, suggested that the results could be harmonised by assuming that the individual motions of the stars take place in the plane of the Milky Way, "some in the direct sense and others in the retrograde sense," and that the Sun moves in a plane which makes an angle of seventeen degrees with the plane of the Milky Way. Nine years later Kapteyn announced one of the greatest discoveries in modern astronomy. It had been believed from the time of Herschel that when the parallactic motions of the stars—the apparent motions due to the Sun's drift in the opposite direction—were eliminated, the individual motions of the stars would be bound to be at random. Kobold doubted this supposition, but it was Kapteyn who first showed it to be quite untenable. After eliminating the parallactic components of the stars in Bradley's catalogue, Kapteyn found that the individual motions fell into two favoured directions—opposite to each other—in the galactic plane. This result showed clearly that the galactic plane is certainly the "ecliptic of the stars," the fundamental reference plane of the stellar system. It also shows that the brighter and nearer stars belong to one or other of two vast streams of stars meeting and interpenetrating in space. The later work of Eddington and Dyson not only confirmed Kapteyn's great discovery, but showed that the fainter stars also—stars down to the ninth magnitude—belong to one or other of the streams. Later on Campbell, the distinguished American astronomer, adduced further evidence of the existence of the two star-streams as a result of his discussion of radial velocities determined spectrographically.

From "Knowledge."] [Photo by Professor Max Wolf.

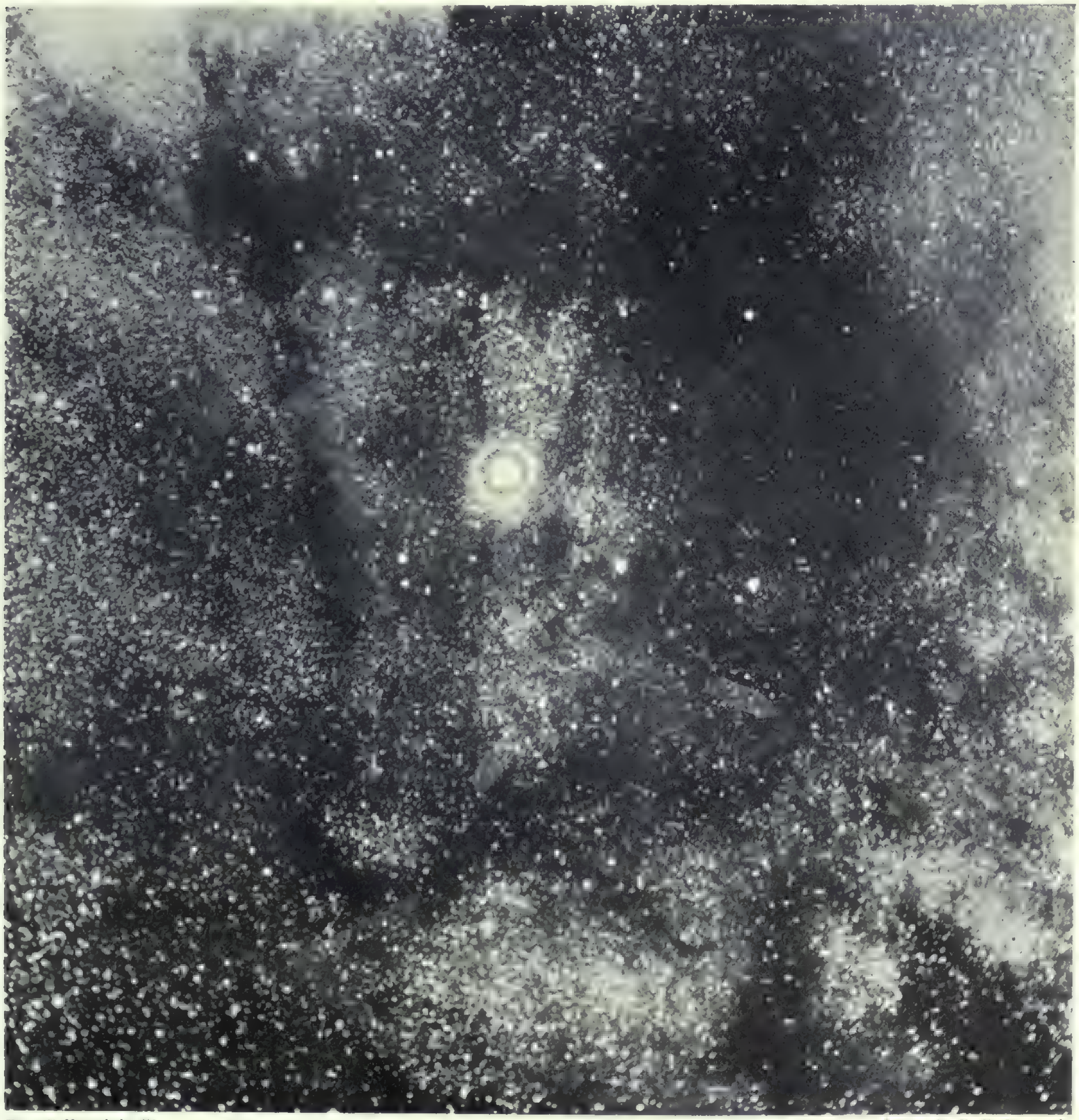
REGION IN PERSEUS.

The constellation Perseus is one of the most prominent of the northern star-groups. It contains a number of bright stars, the most famous being Algol, the well-known variable. This photograph represents a galactic field in Perseus.

The fact of star-streaming being established, the question arises of its true significance. Does it indicate that the stellar system is not a unity, but a duality? Various theories have been put forward to reconcile the observed duality with the unitary interpretation of the stellar system which theory seems to demand. Eddington pointed out, however, as far back as 1911, that the two star-streams probably involve about half a million of the stars around us; but that there is no evidence that they prevail in the extremely remote parts. And the phenomenon of star-streaming is reasonably explained by Professor Shapley's hypothesis of the existence of a local cluster. The interpenetration of this cluster with the general galactic stars gives rise to the observed preferential motions in two favoured directions. "When the local cluster moves," says Shapley, "the inevitable result is star-streaming—a preferential drift in the direction of the cluster's motion for cluster stars, and in the opposite direction for stars of the field."

Soon after the application of the spectroscope to astronomy and the classification by Secchi of the stars into four types according to their spectra, it was noticed that the proper motions varied for the different types. Stars of the second or solar type were observed to have larger proper motions on the average than these of the first. Spectroscopic work on the radial velocities of great numbers of stars

confirmed this. Indeed, in 1910 Kapteyn and Campbell independently announced the significant discovery that on the average the radial velocities of the stars of the so-called later types were greater than those of the earlier types. The average linear velocity, in fact, was shown to increase from one type to another. When the discovery was first announced, it was believed to indicate that as a star



From "Knowledge."] [*Photo by E. E. Barnard.*

THE MILKY WAY NEAR THETA OPHIUCHI.

The Galaxy divides in Cygnus and one of the streams runs through the constellation Ophiuchus. This photograph represents one of the most complex and beautiful regions of that constellation. The bright star near the centre is Theta Ophiuchi, a B-star intensely hot. There are many dark lanes and vacuities in Ophiuchus, some of which are shown on the plate. These long engaged the attention of the late Professor Barnard, who established the fact that much of the darkness is due not to absence of stars, but to the presence of dark nebulous matter.

grew older its speed increased; at that time it was assumed that the Harvard sequence—types B A F G K M—represented the order of stellar evolution. Since then, the new theory of evolution, associated

with the name of Professor Russell, according to which the stars first pass through the giant stage, and secondly through the dwarf stage, has rendered the evolutionary explanation of the increase of velocity with spectral type untenable. More recent research would indicate that this increase of speed with type is a particular manifestation of a wider generalisation—namely, the increase of speed with diminishing absolute magnitudes and therefore with diminishing mass. The blue stars of the so-called early type which have small individual velocities, are bodies of enormous mass, while the yellower stars which form the bulk of the later types are bodies considerably less massive. As Russell truly remarked some years ago, " a correlation of mass and velocity seems more probable than one between temperature and velocity or velocity and age."

We must not imagine, however, that every star of large mass has a small velocity, and that every star of small mass moves at high speed.

PROFESSOR HARLOW SHAPLEY,
the director of the Harvard College Observatory, is one of the most brilliant astronomers of the day. Born at Nashville, Missouri, in 1885, he was from 1914 to 1921 on the staff of the Mount Wilson Observatory, where he commenced his epoch-making work on star-clusters.

PROFESSOR HUGO SEELIGER,
Director of the Munich Observatory and President of the Astronomische Gesselschaft, was born in 1849. He carried through, in the years 1884 to 1898, an elaborate series of studies of stellar distribution. He is the author of one of the chief theories of temporary stars.

Thus, one of the most massive stars known, Y Cygni, moves with a great velocity, and Shapley has pointed out that the long period variables of spectral class M are giants and have peculiarly high radial velocities. Thus large proper motions are not incompatible with high luminosity. Such rapidly-moving giant stars may, of course, be exceptional, indeed, appear to be so, and there may be some explanation of their peculiarly rapid motions.

The velocities of individual stars and of clusters and groups depend not only on their masses, but on the external influences which have been brought to bear on them. The motions of the stars are what they are, their speeds and directions of motion have their present values, because of the forces which have been influencing them during myriads of years. According to the speculations of Dr. Shapley, which are based on a careful study of observational data, the stellar system as we know it is the outcome of the union of numerous clusters. The Universe known to us

From "Knowledge."] [*Photo by Alex. Smith.*

THE VICINITY OF BETA CYGNI.

This photograph represents a region of the Galaxy where the stars are much less profusely scattered than in other regions of the heavens. The bright star is Beta Cygni, one of the most beautiful double stars in the entire sky, which is a charming spectacle as seen through a small telescope. The chief component, of the third magnitude, is topaz yellow; and the smaller star is sapphire blue.

From "Knowledge."] [Photo by Professor Max Wolf.

REGION IN CYGNUS.

This photograph represents one of the richest regions in the constellation Cygnus. Each of the tiny points of light on the plate is a sun, and many of these suns—probably the majority—are giants, far surpassing our Sun in volume and luminosity. A small nebula is also shown on the plate. The dark spaces, void of stars, are also to be noted. Probably we have here evidence of the existence of masses of dark matter, not near enough to bright stars to be excited to luminosity.

consists of a long flat disc of stars ; and on either side of this disc are an equal number of much smaller and more compact sub-systems--the globular clusters. Dr. Shapley, in the course of his work, was impressed by the absence of globular clusters from the mid-galactic regions, a fact which in his view cannot be explained only by the presence of dark obscuring matter in these regions. Dr. Slipher's measurements of the radial velocities of globular clusters indicate a preponderating motion of approach, and this suggested to Dr. Shapley that the globular clusters are being drawn into the greater galactic system. Support is accorded to this view by the fact that the globular clusters nearest to the galactic plane are the least condensed. The stars comprising these clusters would seem to be dispersing under the overwhelming gravitational force of the stellar system. On this view, the numerous open clusters which exist among the galactic star-fields are simply globular clusters which have been drawn into the greater stellar system. When a globular cluster is thus sucked into the vortex, two results follow.

THE STAR-CLOUDS OF THE GALAXY IN SAGITTARIUS AND SERPENS.
This fine photograph, by Dr. Max Wolf, shows the star-clouds in the direction of the supposed centre of the Stellar System. In the Sagittarius clouds, Dr. Shapley detected faint blue stars, which are obviously giants, and the distance of these is so vast that light requires 15,000 years to travel from them to our Earth.

" Faint stars in globular clusters are of small mass and of more than average velocity, and in their orbital motions frequently attain great distances from the centre. When the globular cluster approaches a disturbing body as massive as the general galactic system, such stars are of course most readily lost and intermingled with galactic stars. On the other hand, the massive cluster stars, which are mostly of high luminosity, having low peculiar velocities and maintaining in their sub-system a high degree of stability, retain their organisation longer in a disrupting field." This suggests that the local cluster of which our Sun is now a component may have originally formed part of a globular cluster which, like others, has been absorbed by the greater system. Indeed, the galactic system may have originated in the intermingling of two clusters, and may have grown to its present huge

dimensions by swallowing up other clusters—a process which, if Dr. Shapley's hypothesis be in the main correct, is still proceeding. The time required for this vast cosmic process is almost inconceivable ; thousands of millions of years is an estimate which probably errs on the side of caution.

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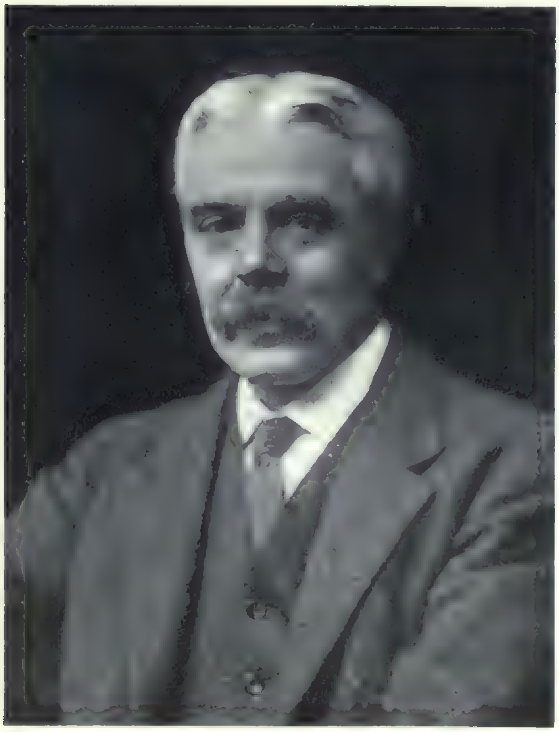
Is this Universe the only one ? Or, rather, is the vast cluster of clusters which we call the stellar system, with its subordinate satellite systems, the globular clusters, the only universe so far as we are concerned ? Do external universes exist ? The question of island universes has bulked largely in astronomical thought since the time of Herschel. As has been noted, that great astronomer originally believed that such universes did exist. Indeed, the hypothesis of island universes was the natural corollary of the disc-theory as first propounded. The resolvable clusters were the nearer universes, the irresolvable nebulæ the more distant. After Herschel had developed his nebular theory of stellar evolution —a theory which entailed the existence of gaseous nebulæ—the conception of "island universes" dropped out of the place which it formerly held in his thought. After his death, however, the hypothesis was revived, the chief reason for its revival being the resolution of some nebulæ, which had defied Herschel's reflectors, and the supposed resolution of others by the great Rosse reflector and the large refractors of Harvard and Pulkova. The pendulum of astronomical opinion, however, swung violently in the opposite direction after the demonstration by Huggins and the early spectroscopists of the truly gaseous nature of some of the most prominent nebular objects. By the end of the last century the question was regarded as practically closed. The vast majority of astronomers were prepared to subscribe to Proctor's dictum that "all the nebulæ hitherto discovered, whether gaseous or stellar, irregular, planetary, ring-formed, or elliptic, exist within the limits of the sidereal system."

PROFESSOR MAX WOLF.

Dr. Max Wolf, Professor of Astronomy at Heidelberg and Director of the Astrophysical Observatory there, was born in 1863. His chief work has been in astronomical photography. He first drew attention to the dark markings in the Galaxy, which are now believed to be non-luminous nebulæ.



Photo] [*Russell, London.*

SIR F. W. DYSON.

As Astronomer Royal, Sir Frank Dyson has held the Directorship of the Royal Observatory, Greenwich, since 1910. His researches in stellar motions and distances have materially added to our knowledge of the structure of the Universe.

From "Knowledge."] [Photo by Professor Max Wolf.

THE PLEIADES.

This star-group is one of the best-known of all celestial objects, and has been known from the earliest ages. Indeed, it is referred to in the works of Hesiod, and in the Books of Amos and Job. During the Nineteenth Century the Pleiades came much into notice because of Madler's famous hypothesis that Alcyone, the brightest star of the group, was the centre of gravity of the Stellar System. In 1859 a faint nebulosity was detected in the cluster by Tempel, at Florence. Photography shows this nebula to be of vast extent. In 1912 Dr. V. M. Slipher, of the Lowell Observatory, showed that the nebula is actually dark and shines by the reflected light of the involved stars.

Of the various classes into which the nebulæ are now divided, the irregular nebulæ—bright and dark—and the planetaries unquestionably belong to our stellar system. Their concentration to the plane of the Galaxy and the plane of the local cluster places this beyond question. But the status of the large and important class of spiral nebulæ is by no means so easily decided. Their spectra differ from those of the irregular and planetary nebulæ. The typical spectrum of the spirals is continuous. Also, they are sharply differentiated from the ordinary gaseous nebulæ by their motions. Dr. Slipher, director of the Lowell Observatory, has shown that "the average velocity of the spirals is about twenty-five times the average stellar velocity." Still more remarkable is their distribution over the sky. While the planetary and irregular nebulæ are aggregated towards the galactic plane, the spirals avoid the fundamental plane of the stellar system altogether and are most numerous near the galactic poles. When these facts were first ascertained, they seemed to point to the extra-galactic, non-nebular nature of the spirals, and accordingly the hypothesis of island universes was revived. On this interpretation of their nature, the spirals are galaxies coequal in size with our galactic system, and are placed at so great a distance—at a distance of the order of a million or millions of light-years—that they cannot be resolved into their constituent stars.

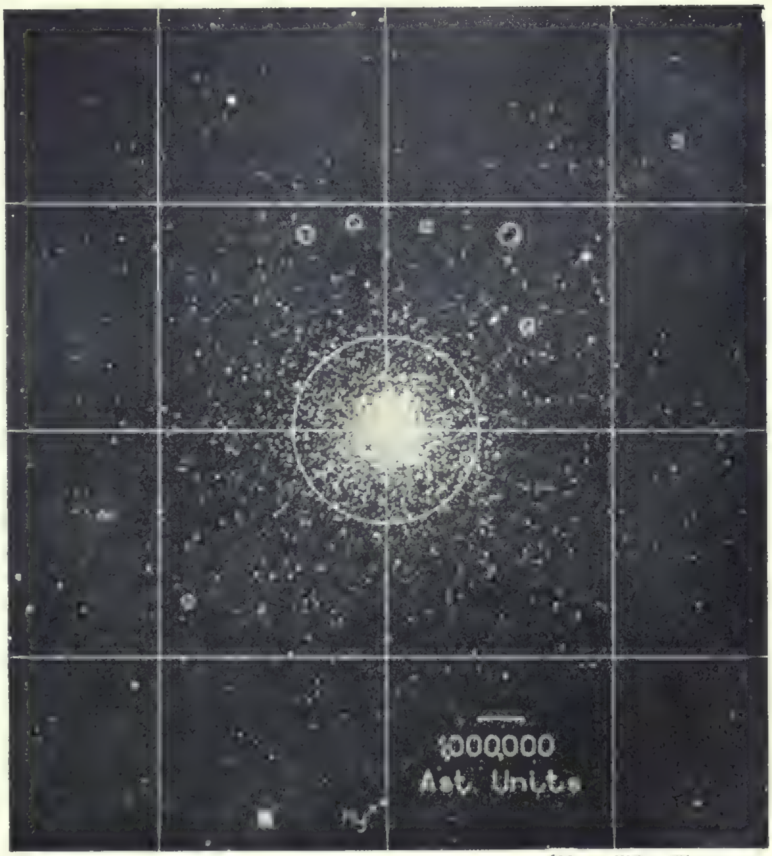
On a first consideration the theory is attractive and it is still maintained by a number of astronomers. But there are grave objections and on the whole the balance of evidence is hostile. If these spirals are external universes, why do they congregate round about the galactic poles? Why are they distributed in a manner which suggests that they are influenced by the stellar system? Were they actually island universes, coequal with ours, their distribution should be at random and should certainly have no reference to the galactic plane. We are driven to conclude, therefore, that the spiral and other non-galactic nebulæ are intimately related to and form part of, the stellar system. Their enormous velocities of recession from our system suggests that they are composed of material specially

From "Knowledge." *Photo by Professor Keeler.*

THE GREAT CLUSTER (M.13) IN HERCULES.

The great Hercules Cluster is the finest example of a globular cluster in the northern celestial hemisphere. It was first noted in 1716 by Halley, who described it as "a little patch," and again in 1784 by Messier, in whose famous catalogue it is numbered 13. For some time the view was held that the cluster consisted of smaller stars than our Sun, closely packed together. Dr. Shapley, however, in his exhaustive study, established the fact that the brighter stars in the cluster are giants. He has measured the distance of the cluster and finds it to be a sub-system, dependent on the galactic system, 36,000 light-years away.

susceptible to the radiation pressure of light. At all events, it seems most improbable that these nebulæ are external universes. But this fact does not preclude the possibility that away out in space, situated at distances far beyond the light-grasping power of the largest telescope, other collections of stars of the same order of magnitude as our galactic system may exist. On the other hand, Professor Einstein concludes from his general theory of relativity that the universe is "finite yet unbounded." It is deduced from the theory that space is curved—spherical or elliptical. It is of finite volume and has no bounds. The difficulty of such a conception, as Professor Eddington remarks, is "that we try to realise this spherical world by imagining how it would appear to us and to our measurements. There has been nothing in our experience to compare it with, and it seems fantastic. But if we could get rid of the personal point of view and regard the sphericity of the world as a statement of the type of order of events outside us, we should think that it was a simple and natural order which is as likely as any other to occur in the world." On the assumption that the Universe is finite, its size has been computed by Einstein and De Sitter. Both agree that a ray of light would require 1,000 million years to go "round the world." If a light-ray could really perform such a journey some remarkable results would follow. After 1,000 million years the rays of sunlight and starlight would return to their starting points. Thus, theoretically, the sky should be covered with "stellar ghosts" occupying the positions which Sun and stars filled 1,000, 2,000 or 3,000 millions of years previously. It has been suggested that perhaps one or more of the spiral nebulæ are really phantoms of our own stellar system. The likelihood of this happening, however, is very slight. It is most improbable that the rays of light, after so long a journey would converge at the very point where they diverged. Theoretically it is possible, but the probability is that the light would either be absorbed or scattered or else deflected by the various gravitational fields scattered throughout space.



[*Mount Wilson Observatory.*

THE GLOBULAR CLUSTER M.3 (N.G.C. 5272).
The side of a square represents 5,000,000 times the Earth's distance from the Sun, and a diameter of the large circle 65 light-years. The letters Hy show the distance of the Hyades from the Sun if placed at the centre, and the x the distance of Sirius. Stars enclosed are typical variables.

Even if we grant the finitude of the Universe, which the general theory of relativity seems to necessitate, we are left face to face with a Cosmos so vast as to baffle the imagination. A light-year is equivalent to about six billion miles ; a universe of the extent of a thousand million light-years is of the order of the infinite in comparison with the tiny globule on which we spend our fleeting lives. The contemplation of the Universe of stars drives home upon us with terrific force the utter insignificance of the planet on which we live, and which is all the world to the vast majority of

mankind. As Flammarion truly says, " in the eternity of duration, the life of our proud humanity, with all its religious and political history, the whole life of our entire planet, is the dream of a moment " ; and if the overwhelming vastness of the created universe oppresses us, it likewise compels us to bow our heads in reverence before the Immeasurable Power which finds expression in this magnificent Cosmos, with its almost infinite profusion of shining suns.

CHAPTER XVII.

THE ANCIENT CONSTELLATION FIGURES.

BY A. C. D. CROMMELIN, B.A., D.Sc., F.R.A.S.

IT is well to begin this chapter with the statement that an account of ancient Astronomy cannot possibly be so definite or certain as one that relates to the present epoch. For the period commencing about 500 B.C. we possess some fairly full documents, that enable us to form a clear picture of the astronomical conceptions of the writers. But for earlier epochs, systematic treatises are wholly lacking, and we have to form our ideas of the condition of Astronomy by piecing together a number of fragmentary and isolated statements ; we can often make useful conjectures, based on our knowledge of the subsequent course of events, but these must remain provisional. Astronomy is truly called the oldest of the sciences, for the motions of the Sun and Moon affect the course of human life in so many ways (and did so still more in the simpler conditions of primitive life) that the importance of finding out the periods and laws of their revolutions must have been recognised very early ; this would involve the mapping out of the principal star groups, since these would be required as points of reference. Probably the same facts were in many cases learnt independently in different countries.

[E.N.A.

CHINESE CELESTIAL GLOBE AND QUADRANT.

Save for the dragon-embellishment, so popular in China, and the absence of a telescope, the quadrant is quite similar to that used by Bradley at Greenwich. The celestial globes were probably used, *inter alia*, to facilitate the observation of heliacal rising, by indicating the exact direction in which to look for the star.

One of the early problems was to reconcile the lunar month with the solar year. The majority of ancient nations used the lunar month, whose length alternated between twenty-nine and thirty days, and they inserted a thirteenth month occasionally to preserve the correspondence with the solar year. The cycle of nineteen years, known as Meton's, was adopted independently in several countries ; it contains seven " full " years with thirteen months and twelve " common " ones. The Golden Numbers recording the position of each year in this cycle are still used in the determination of Easter. One of the greatest of the ancient peoples, the Egyptians, did not use the lunar months, but made their year consist of 365 days, being twelve months of thirty days each, and five extra days. It was found in early times that the 365-day year was too short, in fact, it was noticed in Egypt that the seasons went right round the calendar months in about 1,460 years ; this period is sometimes called a Sothic cycle, from Sothis, the Egyptian name for Sirius, the brightest of the fixed stars. Apparently the first Sothic cycle began when the heliacal rising of Sirius fell on the first day of the Egyptian year. The heliacal rising was

defined as that in which the star was just observable in the morning twilight before sunrise. From later records we deduce that the Egyptians could observe Sirius when the sun was ten and a half degrees below the horizon at the time the star rose ; this is the value used in calculating the dates. The authors of " The Cambridge Ancient History," vol. 1, adopt the date 4241 B.C. for the beginning of the first Sothic cycle ; an approximate calculation of my own, with allowance for the star's precession and proper motion, makes the date thirty-two years later, the difference being merely nominal. This is much the earliest date at which we have any evidence of star observations ; it must be noted that we have no contemporary record of the fact ; it is only carried back by inference from records of a much later date (about 2000 B.C.).

The next date at which we have indirect evidence of star observations having been made is 3400 B.C. The reasons for concluding that the great pyramid was built about this date, and that the star Thuban in the Dragon, which was then the Pole Star, was used in orienting the building, were given on page 238.

We have, therefore, good reasons for believing that the stars had already been mapped out to some extent in 4000 B.C., and that the character both of their daily and annual motions was understood. The recognition by the Egyptians of the advantage of using a star near the pole for laying out a north and south line shows considerable mathematical skill, which is further proved by many details in the structure of the pyramid.

From] [" L'Astronomie."

ORION AND SIRIUS ON THE DENDERAH STRAIGHT ZODIAC.

The second figure from the right represents Orion. Sirius is portrayed as a kneeling cow with a star between its horns. The Egyptians paid great attention to observing the day when Sirius, which they called Sothis, rose just before the Sun. This day occurred in the month now called July, about the time of the rising of the Nile. The latter is symbolised by the water which the figure on the left is pouring out. The Sothic cycle of 1,460 years was the period in which this day travelled round the Egyptian year of 365 days.

It is probable that the constellation figures adopted in Egypt at the time of building the pyramids, and for long afterwards, were entirely independent of those adopted in Western Asia. The very fact of their year being a 365-day one, unconnected with the lunar months, would show this independence. We have not, however, sufficient data to reconstruct the old Egyptian constellations ; those that have come down to us are of a later period, and are largely modified by Mesopotamian influence. Thus, the twelve zodiacal constellations in the Denderah Planisphere, whose date is 36 B.C., are practically the same as those of Aratus and Ptolemy save that the newly-devised Scales replace the Claws of the Scorpion ; but the remaining constellations show notable departures from them. Thus the Great Dog is replaced by a cow kneeling in a boat, with Sirius between its horns. There is also a figure of a Hippopotamus above the Scales.

C. Detaille, who describes the Denderah planisphere in " L'Astronomie," vol. 7, makes the following remarks on the character of Egyptian Astronomy, which seem to apply to many, though perhaps not to all, of its adherents. " The ancient Egyptians were astrologers, not astronomers : they were unable

From] [" L'Astronomie."

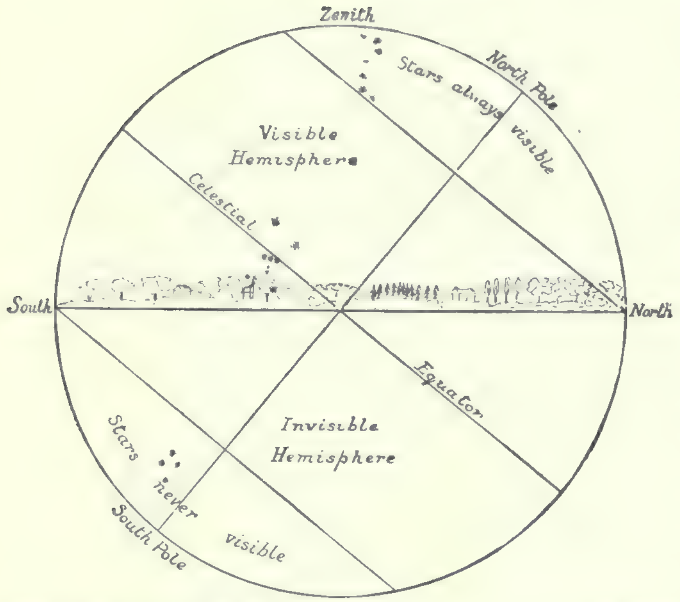
THE DENDERAH CIRCULAR ZODIAC: THE SCALES TO THE FISHES.

The original Egyptian Zodiacal figures have not come down to us. Those on the Denderah Zodiac (date 36 B.C.) are the familiar figures designed in Mesopotamia and still in use to-day. The Egyptians have, however, varied the attitudes of the figures. The Scales point in a different direction, the Waterman's vessel and stream of water are on the reverse side of his body; the Zodiacal Fishes swim in parallel directions instead of divergent ones. The figures outside the zodiac (except the southern fish, which was regarded as part of the Waterman) are Egyptian. Note the Hippopotamus in the centre, and the Ape under the Scorpion. The Lion near the Scales is not the Zodiacal Lion.

From] [" L'Astronomie."

THE DENDERAH CIRCULAR ZODIAC: THE RAM TO THE VIRGIN.

The designers of this famous zodiac were Astrologers rather than Astronomers. They thought more of the animal figures than of the stars themselves. Hence it was a matter of indifference to them in what attitude they placed the figures. The Ram and the Bull are both reversed from their normal pose, and the figure of the Bull is complete, not the usual half figure. The pose of the Virgin is curious; she stands on the Lion's tail, which she grasps with her hand. Hydra and the Raven are in fairly correct positions under the Lion. The representation of Orion and Sirius is not quite identical with that in the straight zodiac (Fig. on page 641). The bow behind Sirius reminds us that "the Bow Star" was one of the Sumerian names of Sirius.



From "Astronomy of the Bible."] [Maunder.

THE CELESTIAL SPHERE IN MID-LATITUDES.

The diagram makes it clear that there is a large region round the north pole, the stars in which never set, and an equally large region round the south pole, the stars in which never rise. The nearer we go to the equator the smaller these regions become. The stars in these regions undergo a very slow change owing to the shift in the places of the north and south celestial poles brought about by precession.

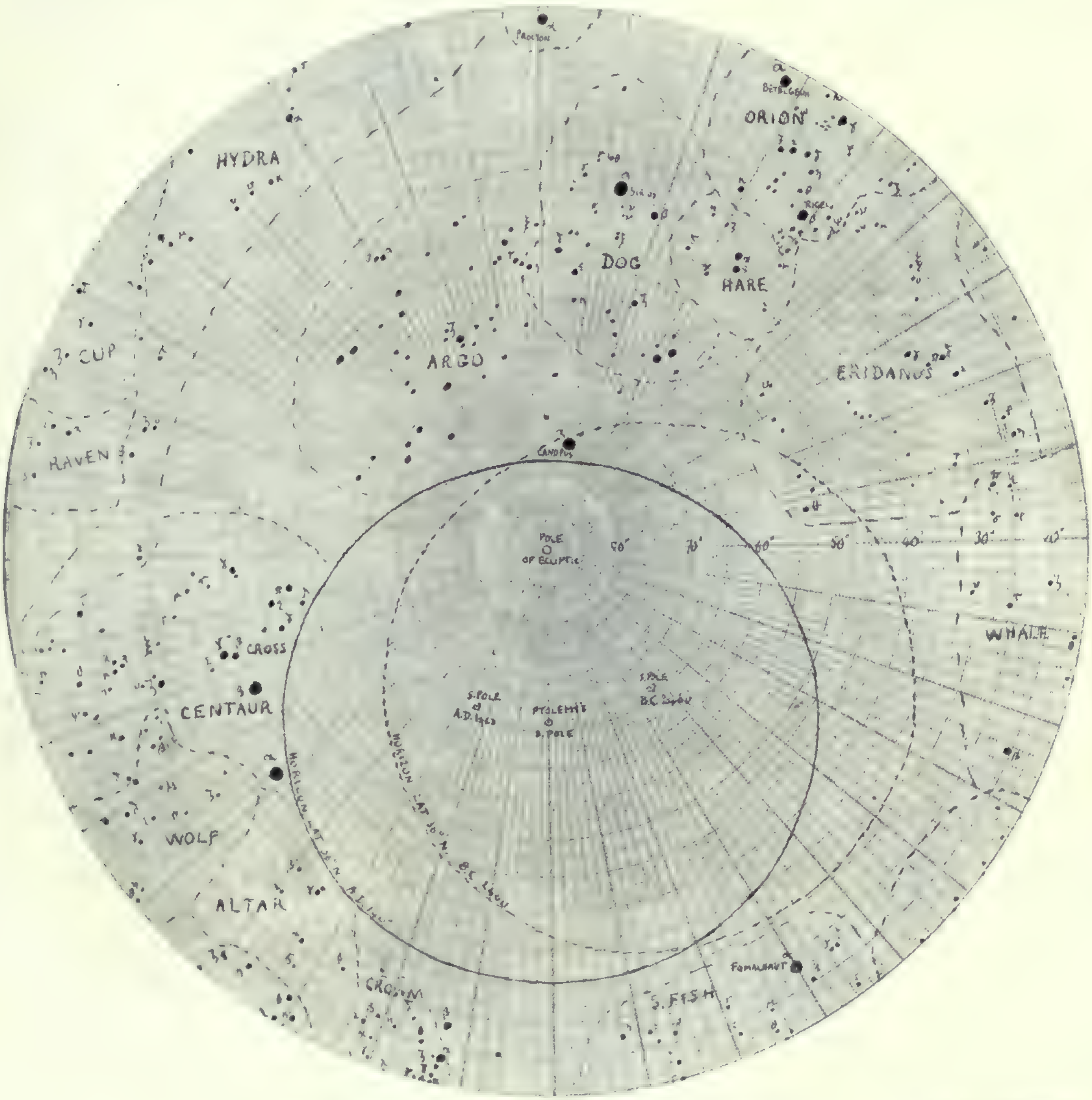
to distinguish the true from the false . . . and they tried to bring the stars under their yoke, to make them serve their passions and their ambitions instead of bowing reverently before the majesty of the Universe, and trying to understand its laws and its grandeur."

The third millenium B.C. must have been a period of great activity both in East and West. The Chinese appear to have deduced fairly accurate values of the periods of the Sun and Moon, enabling them to predict eclipses ; it is also evident that they had mapped out the sky into constellations at least as far back as 2500 B.C. ; this is about the same date as that which we deduce for the adoption of the system of constellations that is still in use amongst European and kindred nations, which is quite independent of the Chinese system. It is very remarkable to find the persistence with which this system (apparently devised in or near Mesopotamia) was adhered to through thousands of years. Thus, the description of several constellations by Homer and Hesiod shows that they divided the heavens in the same way as we do. Centuries later, about 370 B.C., Eudoxus wrote a full description of the whole system ; Aratus in 270 B.C. wrote a poem based on this work of Eudoxus ; this has come down to us, and will be dealt with in detail shortly ; for the present I will note that there are several points in the poem that were not true for the epoch of Aratus ; they had been true when the constellations were framed, but precession had modified them. Hipparchus pointed out this fact, and was led by study of the phenomena to the discovery of precession. The star-catalogue of Hipparchus, which was completed about 127 B.C., has not come down to us in full, but we know that it contained 1,080 stars, grouped in forty-eight constellations, which were those handed down by tradition from a remote past. The catalogue of Claudius Ptolemy, made at Alexandria about the year A.D. 137, contains 1,022 stars, grouped in the same forty-eight constellations ; it is strange that it does not seem to have occurred to Ptolemy to observe stars outside these traditional star-groups, although there were considerable regions of the sky not included in them that were well within his field of vision, notably the region under the Hare and the Whale, where we now have the modern groups of the Dove, the Sculptor, and the Phœnix. This shows the extraordinary tenacity with which the old tradition had been handed down for over 2,000 years ; a fortunate circumstance, since it enables us to form a tolerable estimate of the date when these constellation figures were formed.

I have prepared a map (page 645) showing all the southern stars in Ptolemy's catalogue, in which I have marked by a circle the limit of the region visible in latitude 36° North. The latitude of Alexandria is 31°, but stars cannot be seen right down to the horizon. I have added the corresponding circle for the date 2460 B.C., that is, 2,600 years before Ptolemy; this interval is one-tenth of the great precessional cycle, so that in it the pole moves through thirty-six degrees about the pole of the ecliptic. It will be seen that the circle of 2460 B.C. is equidistant from the lower parts of the Whale and the Centaur ; on the other hand, it cuts off the lower stars of Eridanus, but we cannot include all of these without taking an improbably late date. My selected date is midway between those of R. A. Proctor (2170 B.C.) and

E. W. Maunder (2700 B.C.). The latter date seems to me to cut off too much of Eridanus ; I also think that Mr. Maunder's deduced latitude of the observers who designed the constellations (36° to 40°) is rather too high ; it would exclude Canopus, though this is mentioned by Eratosthenes as one of the stars handed down by tradition ; also it would put Fomalhaut too near the horizon ; this was one of the four " Royal stars " that marked the four seasons, so that it must have been high enough for easy visibility ; I do not therefore feel so sure as Mr. Maunder does that the latitude must be placed north of Babylon.

It is fairly evident that the constellations were not wholly, perhaps not even mainly, designed from



[A. C. D. Crommelin.

MAP OF PTOLEMY'S SOUTHERN STARS.

I have shown in this map the positions as given by Ptolemy of all his stars that are more than fifteen degrees south of the ecliptic. I also show the south pole of our own time, of Ptolemy's time A.D. 140, and of 2460 B.C. ; the last must be close to the epoch when the southern constellations were mapped out by the inhabitants of Mesopotamia. The stars of the Southern Cross are in Ptolemy's Catalogue, but they are considered as part of the Centaur. It will be seen that Ptolemy did not observe stars outside the old constellation-figures, though many such were well placed for observation in his time, in particular the regions under the Whale and the Hare.

fancied resemblances between them and the objects whose names they bear ; there is such resemblance in a few cases (for example, the Great Bear and Orion), but in others the figure was chosen as part of a symbolical scheme.

The most explicit descriptions of the ancient figures have come down to us through the Greeks, though it is evident that they had received the tradition from the East. Eudoxus, a pupil of Plato, brought a celestial globe from Egypt, and wrote a description of the figures upon it. A century later, the king of Macedonia commissioned the young Cilician poet Aratus to put this description into verse, which has fortunately come down to us, and is the earliest extant document that gives a full description of the traditional figures that are associated with the star-groups.

The poem opens with a noble ascription of praise to the Creator, containing the words, " For we are also His offspring," that were quoted by St. Paul at Athens; it then describes the constellations in order, beginning with the two Bears, which are here named Helice and Cynosura ; the use of the Little Bear in navigation is mentioned ; sailors of that epoch, 270 B.C., had not the advantage that we enjoy of a bright star close to the Pole ; Beta of the Little Bear was seven degrees from it (*see* map, page 228).

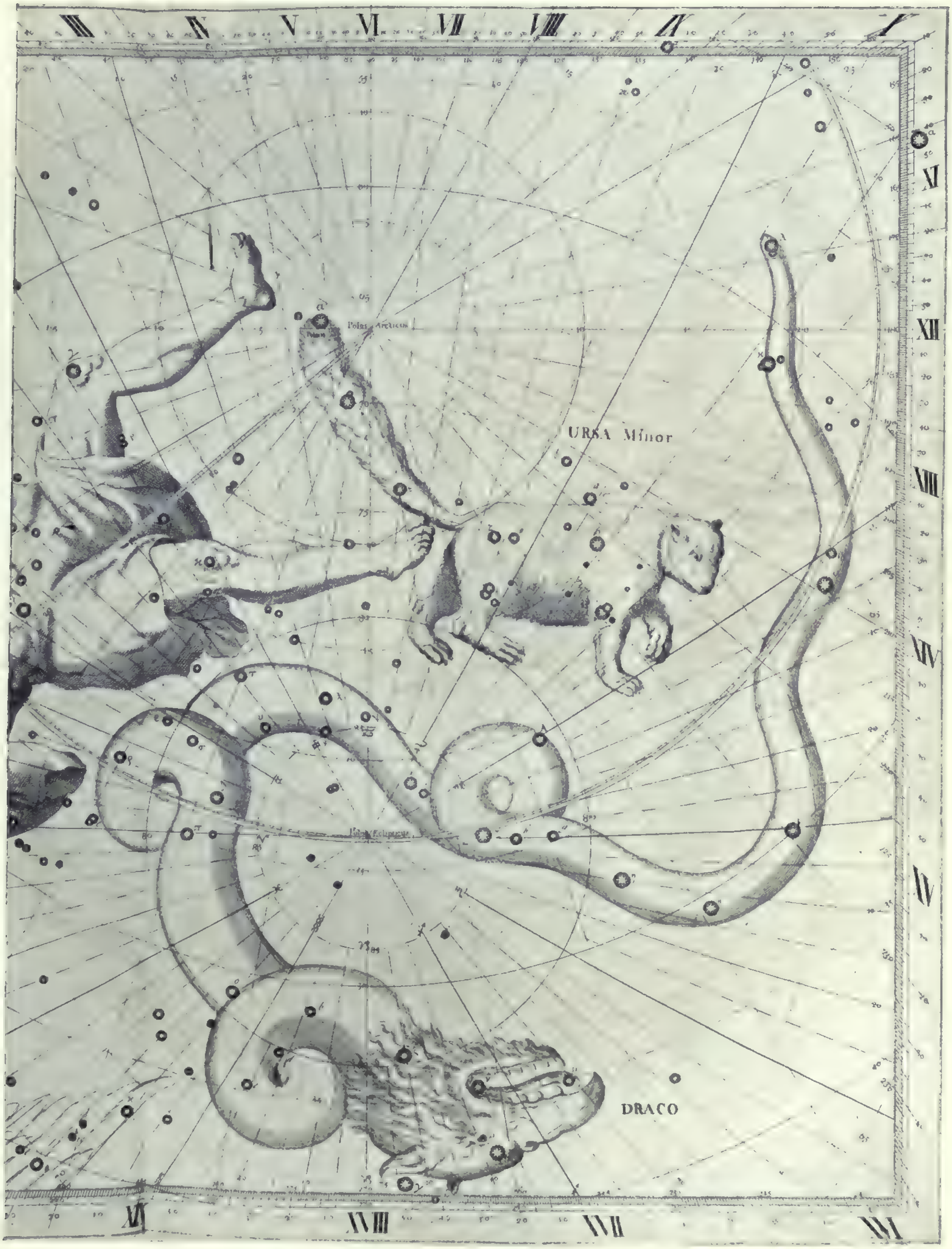
SOUTHERN CONSTELLATIONS.

A portion of Argo is visible in England, the remaining stars in the picture are invisible there. Argo is subdivided into Malus the Mast, Vela the Sails, Puppis the Poop, Carina the Keel or Hull. The Southern Cross was known to the ancient astronomers, being then farther north ; it was included in the Centaur. Tucana, Hydrus, Dorado and the Magellanic Clouds were unknown to the ancients. The name Achernar (Arabic, Last of the River) originally belonged to Theta Eridani, but when the much brighter star in the picture was found, the name was transferred to it.

The Dragon comes next, an important constellation that contains the Pole of the Ecliptic, and also contained that of the Equator at the date when it was mapped out. Mr. Maunder notes that the symbols ☊ ☋ for ascending and descending nodes (*see* page 216) used by astronomers from time immemorial, are representations of the twisted form of the Dragon. It may be mentioned that the star Gamma Draconis, one of the " Eyes charg'd with sparkling fire," passes exactly overhead at Greenwich, and was used by Bradley for testing the laws of aberration and nutation.

Aratus next describes " a Labouring Man in a kneeling attitude " (Greek, " En Gonasin "), with " His right foot on the scaly Dragon's crest " ; many writers take this constellation as depicting the crushing of the serpent's head (Genesis iii. 15). Eratosthenes later called this constellation Hercules (probably because the figures fitted the myth of his fight with the Lernean Hydra), the name it still bears.

R. H. Allen, in " Star names and their meanings," thinks that the pair of star-figures Hercules and the Dragon were among the earliest delineated, and states that a cylinder seal of date between 3000 B.C. and 3500 B.C. shows the device, still familiar to us, of a man kneeling on one knee with his other foot upon the dragon's head. There are two other considerations in favour of this early date ; first we have seen (page 238) that the star Thuban in the Dragon was known in Egypt as the Pole Star about 3400 B.C., when the Great Pyramid was built. Secondly, we now see the figure of Hercules upside-down, for precession has carried it farther from the pole, and it passes to the south of our zenith. But if we go back to 3400 B.C., we find that it would be seen wholly to the north of the zenith in the latitude of



[*Flamsteed's Atlas*.

DRACO, THE DRAGON, AND THE LITTLE BEAR.

The Dragon was a very important constellation to the ancients; it connected together the Poles of the Ecliptic and of the Equator. The latter was marked by the star Thuban, to the right of the Little Bear's head The Dragon's head is marked by three bright stars, not far from Vega. Our present Pole Star is at the end of the Little Bear's tail. Part of Cepheus is also shown.

[Flamsteed's Atlas.

THE CONSTELLATION HERCULES, OR THE KNEELER.

The name Hercules was given by Eratosthenes. Aratus called it En Gonasin, The Kneeler. He is crushing the Dragon's Head with his foot. We now see the figure upside-down, but it was seen erect on the meridian, north of the zenith, by the Babylonians about 3000 B.C. A representation of it has been found on a cylinder seal of that epoch. This and the Dragon are probably the two oldest constellation-figures. The heads of Hercules and Ophiuchus touch each other. The picture includes the Crown, part of Böotes the Herdsman, and the Serpent's Head.

THE STARS FOR JANUARY.

"Our plate shows the aspect of the sky as seen, looking North and South, from Westminster Bridge; but the positions of the stars will be practically the same for any place in the latitude of Great Britain.

The constellations will appear in the positions shown on January 1 at about 11.30 p.m. (Greenwich Mean Time.)

,,	8	,,	11.0 p.m.	,,	,,	,,
,,	15	,,	10.30 p.m.	,,	,,	,,

Babylon, the head of the kneeling figure being nearly overhead. It *must* have been in this situation when it received its name ; the figure of the Kneeler is then not difficult to recognise, as it is when it is seen inverted.

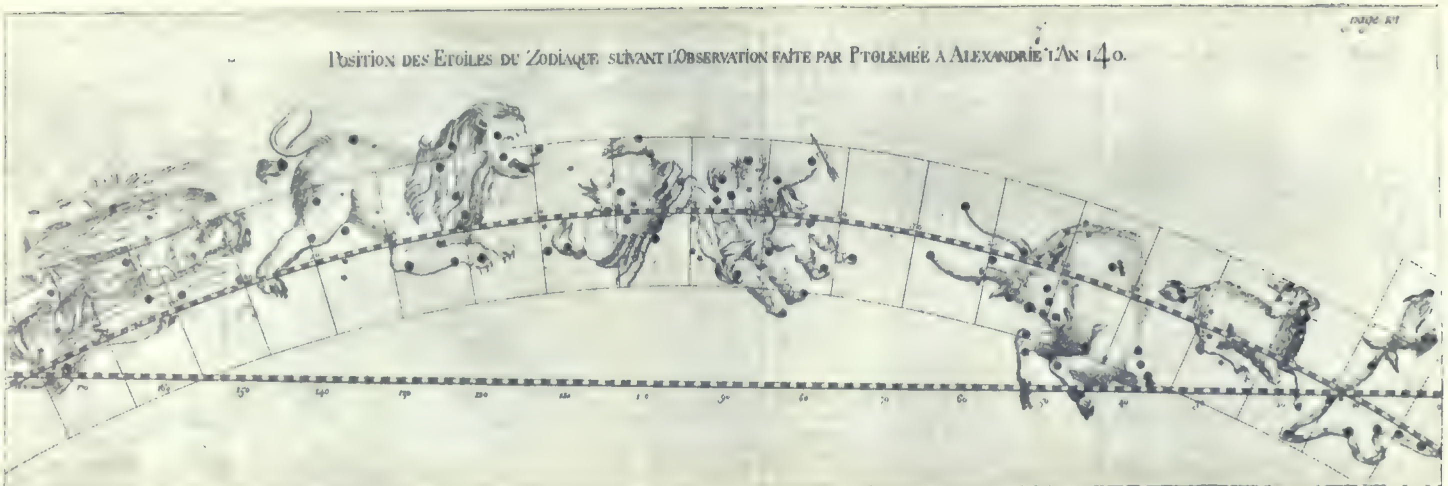
After brief mention of the Northern Crown, Aratus's narrative proceeds to Ophiuchus, the Serpent-Bearer, who holds a huge reptile in his arms ; it " rears its crested head on high, Reaching the seven-starr'd crown in northern sky." Mr. Maunder notes that in 2700 B.C. the head and neck of the Serpent

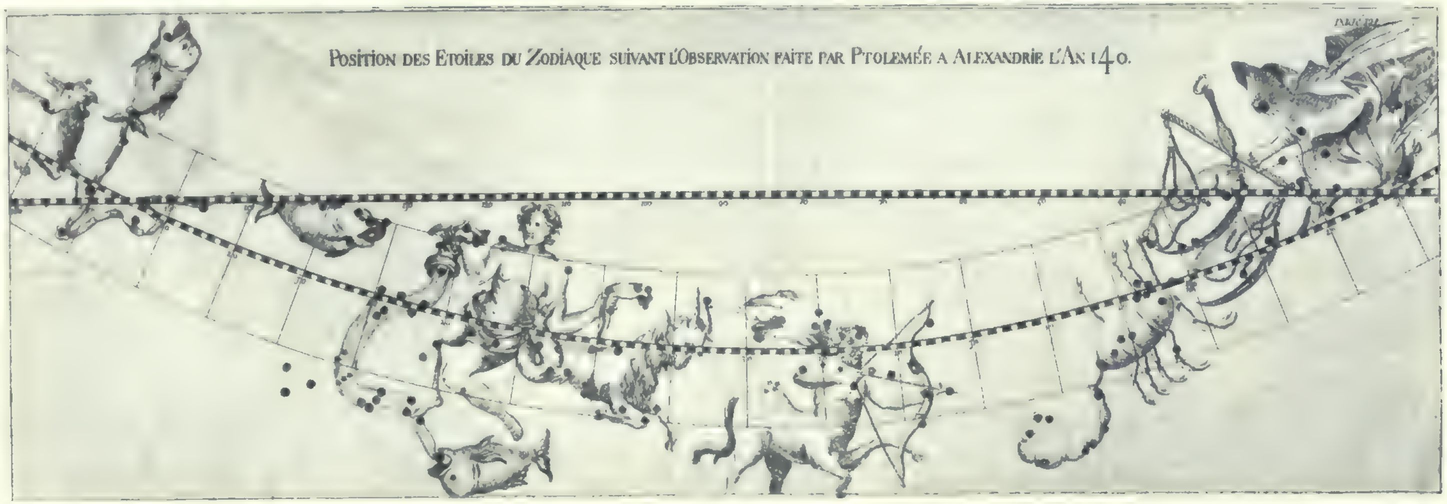
[Flamsteed's Atlas

OPHIUCHUS (THE SERPENT-BEARER) AND THE SERPENT.

There are several great reptiles in the constellation-figures ; most of them marked important points. The Dragon marked the North Pole, Hydra the Equator, the Scorpion's head the Autumn Equinox, and the Serpent's head and neck pointed from the latter to the Pole. Some people have supposed that Ophiuchus and Serpens represent the mythical fight between Marduk and Tiamat. Libra (the Scales) was formerly the Scorpion's Claws. The bow of Sagittarius (the Archer) is seen on the left.

lay along a north and south line that when produced passed through the place of the Sun at the autumn equinox. Aratus notes that Ophiuchus has his feet on the Scorpion, " crushing the monster's eye and plaited breast." The Claws of the Scorpion are next mentioned ; they occupied the place of the group that was renamed Libra, The Scales, in the first century B.C. ; up to that date the Zodiac (Greek for Animal Circle) consisted solely of living creatures.





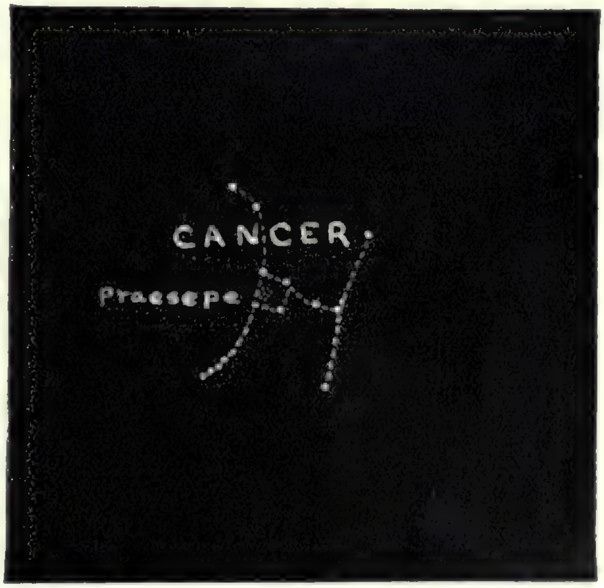
THE TWELVE ZODIACAL CONSTELLATIONS AS DESCRIBED BY PTOLEMY.

Ptolemy did not give actual pictures of the constellations, but his descriptions, and those of Aratus, enable them to be drawn as they were then conceived. All twelve were originally living creatures (hence the name zodiac, meaning animal-circle), but Libra (the Balance) replaced the Scorpion's Claws. The Southern Fish, receiving the stream of water in its mouth, seems to have been looked on as part of the Waterman. Fomalhaut is in its mouth. Note that the Bull, Twins and Crab have their heads eastward; the other heads are westward.

We proceed to Böotes, the Herdsman, which Aratus calls also Arctophylax, the Bear Driver; Arcturus, the leading star, has a similar meaning; our word Arctic is derived from Arctos, a Bear. Böotes has a distant resemblance to Orion, the two constellations being confused by some ancient writers.

The Virgin is identified by Aratus with Astraea, the goddess of Justice: " Justice was shocked—the blood-stained earth she flies—Jove bade her welcome to her native skies." The star Epsilon Virginis is called by Aratus Protrygetor, " Forerunner of the vintage." The Twins, Crab, and Lion are next described; the Lion is associated with the hot season of the harvest. The Charioteer has the Goat (Greek, Aix; Latin, Capella) on his shoulder; the stars below it are called the Kids. A single star serves both as the foot of Auriga, and the upper horn of the Bull; the latter constellation was the first sign of the Zodiac (that is, it contained the point occupied by the Sun at the vernal equinox) when the constellations were named; the tradition remained centuries after this had ceased to be the case: thus Virgil wrote in the Georgics, " The bright Bull opens the year with his golden horns," the year being considered to open at or about the spring equinox. Aratus mentions the cluster of the Hyades in the Bull's Head, but he makes the Pleiades, in its shoulder, a separate constellation; he gives the names of seven Pleiades: Alcyone, Merope, Celaeno, Electra, Sterope, Taygete, Maia. He contradicts the legend that one had vanished; its visibility is merely a test of clearness of sky and keenness of sight.

We next come to the group of six constellations associated with the family of Cepheus: he and his wife Cassiopeia, " In her stately chair," are close together in the northern sky; the bright stars of the latter make a conspicuous W. Their daughter Andromeda is represented as chained to a rock; Aratus mentions the bright star that marks her head (it is the top left-hand star of the square of Pegasus), also her feet, her girdle, and her extended chained arms. Pegasus, the Flying Horse, adjoins Andromeda.



CANCER, THE CRAB.

The stars in the Crab are faint, but it contains the interesting cluster Praesepe, the Manger, visible to the naked eye as a misty patch, often mistaken for a comet by the inexperienced. On either side of it are " the two Asses," Gamma and Delta Cancri. This constellation contained the summer solstice 3,000 years ago, hence the name Tropic of Cancer.

According to legend Pegasus was the flying steed of Bellerophon, who fell from its back and was killed; it is curious that it was designed as upside-down; Aratus makes this clear by saying that the Waterman has his hand on the horse's mane; only the front halves of the figures of Pegasus and Taurus are pictured in the constellations.

It has been suggested by modern writers, that Pegasus was looked on as having brought Perseus, the Rescuer, to the scene; Aratus describes the haste with which Perseus comes, and the cloud of dust he raises; this evidently refers to the brightness of the Milky Way in this region. Note in particular the two great stellar dust clouds whose photograph appears on page 474. Perseus carries the head of the gorgon Medusa, according to Eratosthenes; it is not mentioned by Aratus; the myth relates that the sea-monster was turned to stone at the sight of it. The remarkable variable star Algol (the ghoul, or mischief-maker) is in the gorgon's head.

Cetus, the Whale or Sea-monster, is at some distance below Andromeda, its intended victim; it is appropriately flanked by the river Eridanus, the Fishes, the Waterman, and the Southern Fish; Eratosthenes suggests that the Nile is a better title for the river than Eridanus; it is a very winding

river, and has been lengthened from time to time as precession brought its stars farther north. Ptolemy's Achernar (meaning "The last of the river") marked with the letter Theta on the map, (page 646), was probably invisible to the original designers of the constellation; after Ptolemy's time, the much brighter star now called Achernar was discovered, and the name transferred to it; this discovery made the river seventeen degrees longer.

Proctor mentions ("Origin of the Constellation Figures") that the Sanscrit names and figures of the six constellations belonging to the Cepheus theme, that were current in India, resembled the Greek

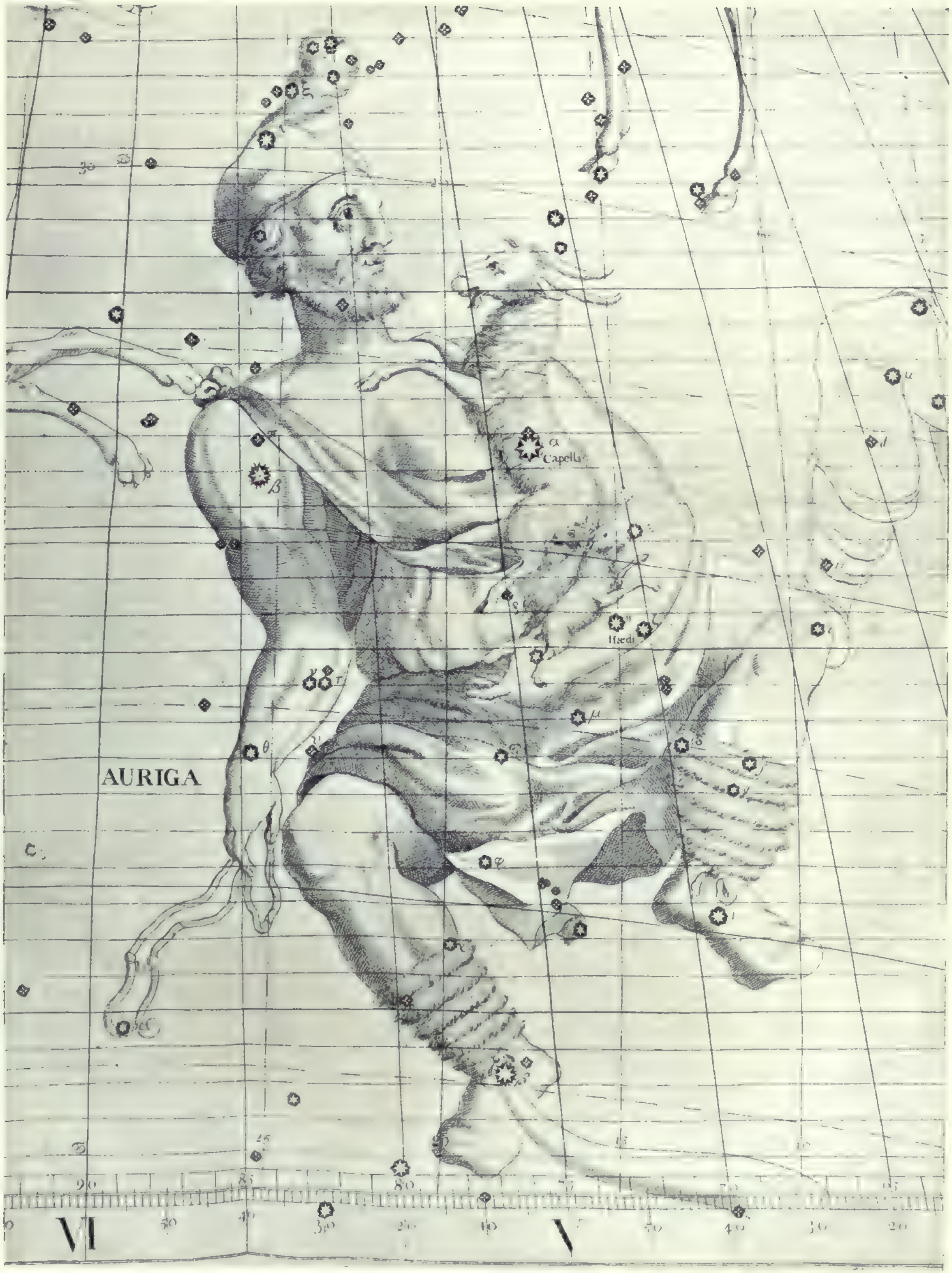
[*Flamsteed's Atlas.*

THE CONSTELLATION PEGASUS, THE FLYING HORSE OF BELLEROPHON.

This constellation, like Hercules, is seen upside down; but unlike Hercules it was never seen erect by the ancients. However, the head, neck and forelegs are so well marked out by stars that the inversion is not important. The hinder part of the horse is not portrayed in the sky. The body includes a large square of bright stars; Alpheratz, the top left-hand one, also belongs to Andromeda. The lower Zodiacal Fish is under the wing of Pegasus.

ones so closely as to leave no doubt of their having had a common origin. There is a tradition that Pythagoras visited India. In any case the Greek names were used in India as early as the fifth century of our era.

It is a debated question whether the constellations were first named from fancied resemblances to certain figures or objects, and the stories relating to these figures composed subsequently, from the



[Flamsteed's Atlas.

AURIGA, THE CHARIOTEER.

This constellation which contains a pentagon of bright stars, is just above the Bull: a single star serves for the tip of the Bull's horn and the foot of Auriga. Capella, the she-goat, is on his left shoulder; Haedi, the Kids, are just below. The reins are in his right hand. The legs of Perseus and the Giraffe are on the right side of the picture; those of the Lynx on the left. Capella, with Beta, Theta and Iota makes a figure resembling the Southern Cross on a larger scale.

[Flamsteed's Atlas.

PERSEUS AND ANDROMEDA.

Perseus is represented as coming to the rescue of Andromeda. He holds the head of the Gorgon Medusa, which contains the variable star Algol (the Demon). Cassiopeia, the lady in the chair, Andromeda's mother, is at the top; farther left are the Giraffe's legs. The Triangle, Ram and Bull are below.

manner in which the figures were grouped ; or, on the other hand, whether the stories were already known, and the constellations designed in order to illustrate them. Proctor adopted the former view, but the latter seems more probable ; first because the resemblance of the star-group to the object is often very slight (sufficient for adaptation, but insufficient for originally suggesting the name) ; secondly because, as Mr. Maunder shows in " The Astronomy of the Bible," the arrangement of several of the constellations in connected groups appears to form a designed scheme. The pole and the equator were both marked by serpentine forms (the Dragon and Hydra) while the head and neck of the serpent held by Ophiuchus might be said to mark the autumn equinox ; the Whale, another serpentine form, was under the position of the spring equinox.

So when we find a group of constellations illustrating the Deluge narrative we are not to take it that the constellations gave rise to the story, but the converse. This group, like the Cepheus one, numbers six constellations. I believe Dr. John Lamb, the translator of Aratus, was the first to notice its connection with the Deluge narrative. It is strange that Proctor, writing later, claims the idea as his own, though he must have known Lamb's book, as he quotes from it elsewhere. The great constellation Argo, so large that in modern times it has been found convenient to make the Mast, the Sails, the Poop and the Hull separate groups, represents the Ark. It is drawn resting on a mountain. The Raven sent out from it is seen on Hydra's back, devouring its flesh. The Dove, under the Hare, is placed appropriately near the Ark ; it is not, however, one of the ancient constellations.

I may remark that Eratosthenes includes the bright star Canopus in Argo, though it was too far south to be seen in Greece ; he probably learnt of its existence when he was in Egypt.

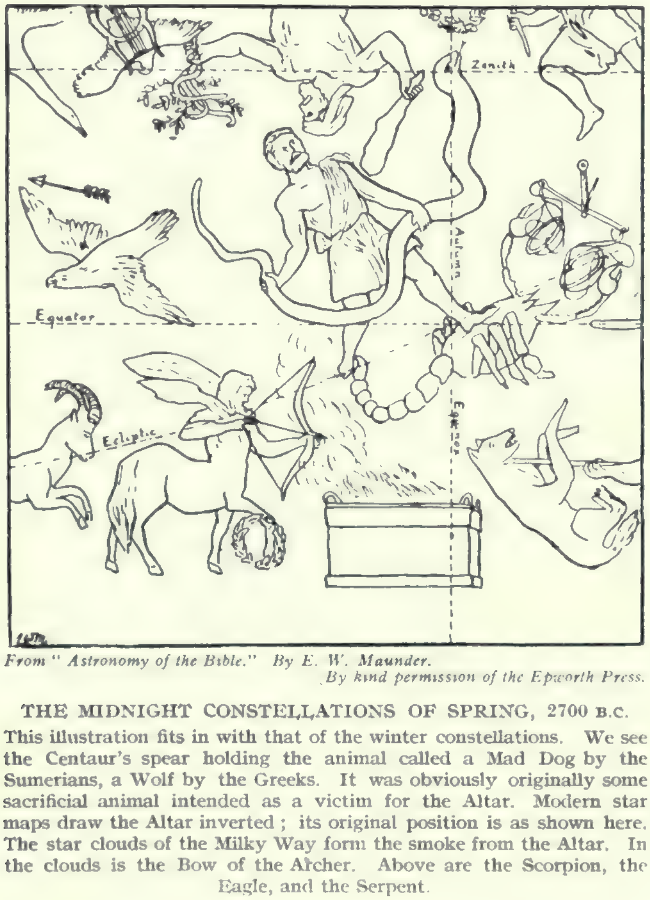
ORION AND LEPUS.

Betelgeuze, from the Arabic Ibt al Jauzah, means Armpit of the Central One. Rigel means a Foot (Hebrew, Regel) ; Bellatrix is Latin for a Female Warrior ; Saiph means Sword. The Sword-Handle contains the Great Nebula, shown by dots under the Belt. The three little stars above Bellatrix give their name to the Chinese lunar mansion Tse, while Tsan is the right-hand star of the Belt. The row of stars above Betelgeuze forms the Club, that to the right of Bellatrix the Lion-skin, formerly drawn as a shield. The chief star of Lepus has the Arabic name Arneb, a Hare (Hebrew, Arnebeth).

The Centaur is an interesting constellation to us, since its brightest star Alpha Centauri is, with one exception, the Sun's nearest stellar neighbour. The star occurs in Ptolemy's catalogue, but its relative nearness to us was not known till about ninety years ago. Ptolemy included in the Centaur the group now known as the Southern Cross, that name not being given for several centuries after his time. (The two stars forming the upright of the Cross are pointers to the south pole, as the well-known stars in the Great Bear are to the north.)

The constellation story differs in one notable respect from those in Genesis and in the Babylonian tablets. They both describe the builder of the Ark as a man, but here he is portrayed as half man, half horse ; the neighbouring constellation Sagittarius, the Archer, is drawn in a similar manner. The Centaur carries a beast (now called Lupus, the Wolf) in his right hand, apparently intended as an offering for the adjoining Altar. Proctor notes that some modern star-maps absurdly draw the Altar upside-down ; it is quite clear that in the time of Aratus its top was to the north. The streams of the Milky Way form the clouds of smoke rising from it ; the Bow of Sagittarius is placed in these clouds. The Southern Crown is under the forefeet of Sagittarius.

Capricornus, the Sea-Goat, is another combination of two different natures, having the fore part of a goat, and the hind part of a fish. As this design is found on some Babylonian boundary stones, it is not a Greek invention ; the Greeks, however, mingled their own mythology with the constellation figures that they took over from the East, identifying the Centaur with Chiron, and the Goat with Pan. The fish's tail may be suggested by the fact that the Goat occurs in the " Watery Region," being followed by the Waterman and the Fishes. The Waterman is pouring a stream of water from his vessel into the mouth of the Southern Fish (distinct from the Zodiacal Fishes). The bright star Fomalhaut marks the Fish's mouth. Ptolemy treated it as belonging to the Waterman ; this accords with its designation as one of the four Royal stars. These originally marked the four seasons : Aldebaran the vernal equinox, Regulus the summer solstice, Antares the autumn equinox, and Fomalhaut the winter solstice ; the respective dates when they occupied these positions are 3000 B.C., 2450 B.C., 3000 B.C., 2500 B.C. The mean is about 2700 B.C., but no stress can be laid on this as determining the exact date of naming the constellations ; for at that remote epoch it appears that the seasons were marked not by the actual conjunction of the Sun with the star, but by the date of the star's heliacal rising.



From " Astronomy of the Bible." By E. W. Maunder.
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THE MIDNIGHT CONSTELLATIONS OF SPRING, 2700 B.C.
This illustration fits in with that of the winter constellations. We see the Centaur's spear holding the animal called a Mad Dog by the Sumerians, a Wolf by the Greeks. It was obviously originally some sacrificial animal intended as a victim for the Altar. Modern star maps draw the Altar inverted ; its original position is as shown here. The star clouds of the Milky Way form the smoke from the Altar. In the clouds is the Bow of the Archer. Above are the Scorpion, the Eagle, and the Serpent.

The zodiacal constellation of the Fishes has contained the equinoctial point since the first century B.C. It is a large constellation ; one of the Fishes is under the square of Pegasus, the other is to the left of that square. They are represented as tied by their tails with long ribbons marked by lines of faint stars ; these ribbons meet at Alpha, the brightest star of the constellation.

The splendid constellation Orion is the centre of another connected group. Orion himself is represented as a hunter. His right arm is raised, brandishing a club ; the left arm holds a lion skin. His belt is marked by three bright stars, and his sword hangs below it. The allied constellations are the Hare, and the greater and lesser Dogs. From his attitude, Orion appears to be specially menacing the Bull, which has lowered its horns as though to meet the attack. Proctor notes that the group is described in the poem known as the " Shield of Hercules " :—

> Men of chase
> Were taking the fleet hares ; two keen-toothed dogs
> Bounded beside.

It is rather singular that almost all the old descriptions describe Sirius, the chief star of the Great Dog, as red. Ptolemy gives it " the colour of fire." Some Babylonian records " the colour of copper." It is now of a brilliant white, and the stages of a star's life are so prolonged that it is difficult to imagine that so great a change in the star's condition could have occurred in 2,000 years ; this interval bears the same sort of proportion to a star's whole career as an hour does to the life of a man.

There is but one more group of constellations to describe ; it comprises the two great birds, the Eagle and the Swan. Aratus gives legends connecting both with Jupiter, the Eagle being said to have carried Ganymede to Olympus. The Lyre is said to have been made by Mercury, who stretched strings across a tortoise-shell ; it contains Vega, the brightest star north of the equator. The Dolphin, a neat compact little group, shaped like a diamond, is said to have been sent by Neptune to bring his bride Amphitrite to him. Near it are the small constellations of the Arrow and the Little Horse (Equuleus).

The following are the lines in which Aratus describes the Milky Way :—

If with admiring ken some cloudless night,
When no full moon obtrudes her jealous light,
To the high heavens thou lift the starry eye,
A radiant girdle belts the azure sky.
A pearly pavement softly bright it seems :
Its silvery whiteness rivals Cynthia's beams.
The Milky Zone, no other circle given,
Thus visible to mortal eye in Heaven.

—Dr. Lamb's translation.

From "Astronomy of the Bible." By E. W. Maunder.]
[By kind permission of the Epworth Press.

THE MIDNIGHT CONSTELLATIONS OF WINTER, 2700 B.C. In the lower right-hand we see the great vessel called Argo by the Greeks, but supposed originally to represent the Ark. It rests on a mountain ; above it is the Water-snake, with the Raven pecking at its flesh. To the left is the Centaur, holding an animal on his spear, obviously intended as a victim for the Altar.

This mention of celestial circles leads Aratus on to trace the positions of the equator, and the tropics of Cancer and Capricorn. He notes that an object on the northern tropic is above the horizon for fifteen hours, one on the southern tropic for nine hours ; this would be the case in latitude 41°, but, as he is probably only using round numbers, we cannot press this closely. Though his descriptions of the positions of the circles are not strictly accurate for his epoch it is of interest to give them.

The tropic of Cancer traversed the heads of the Twins, the knees of the Charioteer, the leg and right shoulder of Perseus, the right arm of Andromeda, the hoofs of Pegasus, the neck of the Swan, the head of Ophiuchus, the body of the Lion, between the eyes of the Crab. The tropic of Capricorn traversed the middle of the Goat, the feet of the Waterman, the tail of the Whale, the Hare, the Dog's legs, Argo, the Centaur's shoulders, the Scorpion's sting, the bow of the Archer.

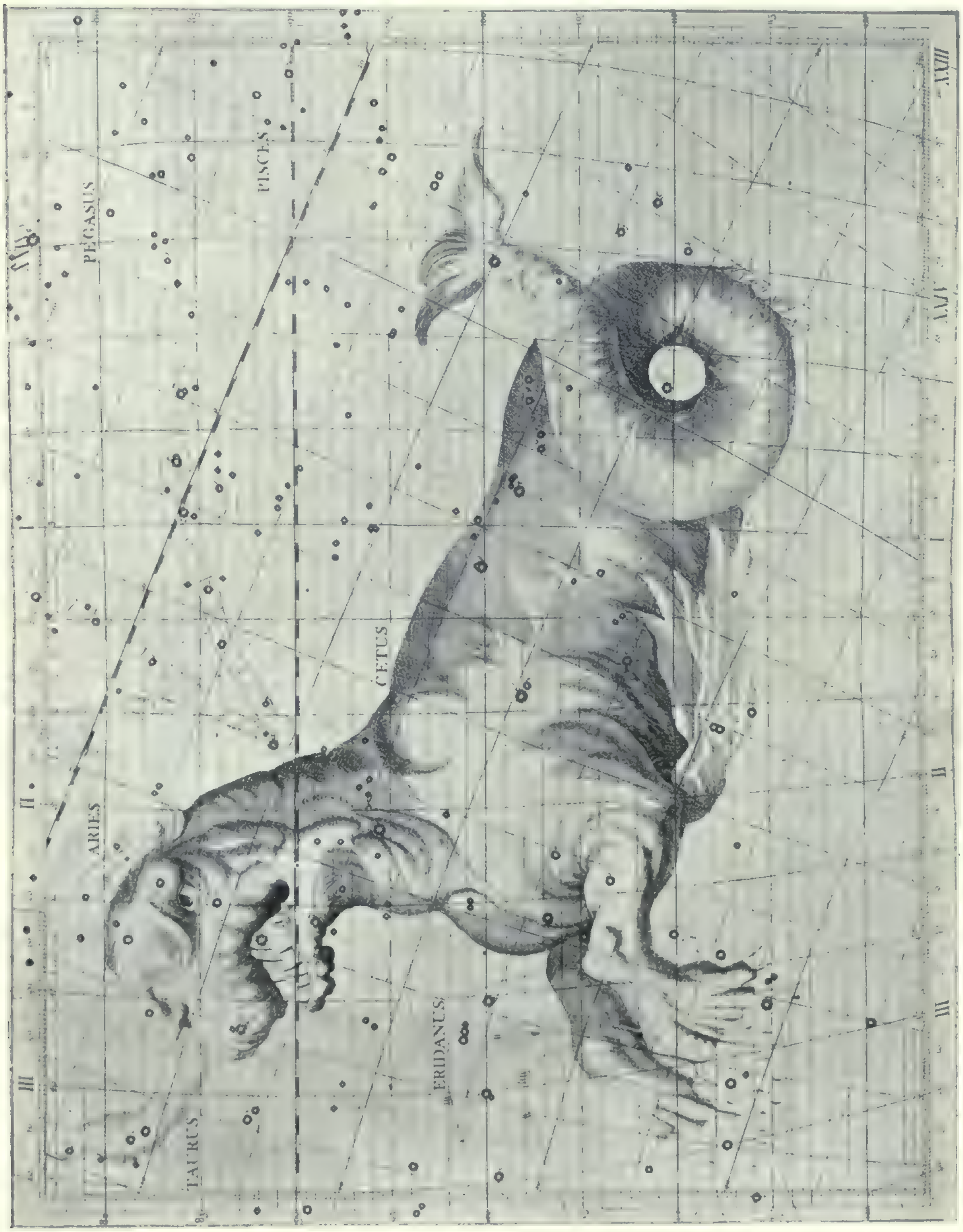
The equator traversed the middle of the Ram, the knees of the Bull, the girdle of Orion, the coils of Hydra, the Cup, the Raven, the Scorpion's claws, the knees of Ophiuchus, the head and neck of Pegasus.

One curious point about the zodiacal constellations is hinted at by Aratus and developed by Manilius. They have their heads westward to meet the Sun, except the three consecutive ones, the Bull, the Twins and the Crab, whose heads are eastward. Manilius suggests that their attitude explains the slower motion of the Sun in that region, of course really due to the Earth's greater distance from the Sun in the northern summer.

The constellation names of Aratus are of Greek origin, with two possible exceptions. Bochart suggests that Pegasus is from the Phœnician Pega, a bridle, and Sus, a horse ; Brown derives the name Orion from the Akkadian Uru-anna, the light of heaven : if this is so, the name came to Greece very early, as it is used by Hesiod and Homer. The star names of Aratus are also Greek; besides the seven Pleiades they are Arcturus, Protrygetor, Aix, Sirius, Procyon ; Eratosthenes adds Canopus, and also the name Stachys, " an ear of corn," the Latin Spica.

The following Latin names are now in use :—Polaris, Capella, Regulus, Castor, Pollux, Bellatrix (Gamma in Orion), Vindemiatrix (Epsilon in the Virgin). Further we use the Greek name Antares, " the rival of Mars," for the bright red star in the Scorpion ; most of the other star names now in use are Arabic.

Having now described the star-groups that were received in Egypt and Greece, I proceed to the Babylonian system, which is presumed to have been the origin of the other. I am indebted for this to Father Kugler's " Sternkunde und Sterndienst in Babel." The origin of the groups went back to



CETUS, THE WHALE.

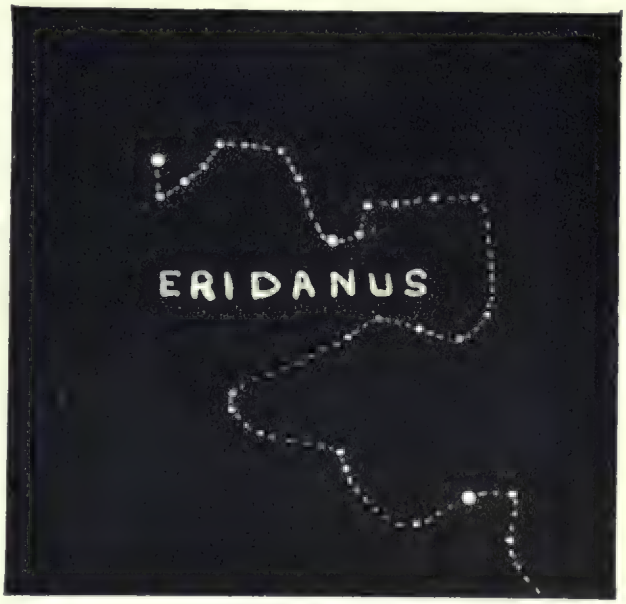
This is the great sea-monster that threatened Andromeda, who was chained to a rock. Perseus, her rescuer, changed the monster to stone by presenting the head of the gorgon Medusa. The river Eridanus flows just in front of Cetus, and extends to the southern horizon, where the Earth appears to swallow it (compare Apoc. XII). Portions of the Fishes, the Ram and the Bull appear at the top of the picture.

Sumerian times, and in most cases the Babylonians continued to use the Sumerian symbols for the names in their cuneiform tablets, though probably they used Babylonian names in speaking. We have a somewhat similar practice ; we generally have Latin constellation names printed on our star-maps, but often turn them into English ones in conversation. (*See* for example page 427, where Aquarius and Piscis are printed on the map, but translated below). Thus, the Scorpion was written Gir-Tab but called Aqrabu ; the latter is practically identical with the Hebrew and Arabic names for a Scorpion ; the Arabic name for Gamma Librae, Zuben Hakrabi, the Scorpion's Claw, is still in general use.

Kugler cites tablets going back into the third millenium B.C. that mention the names of some constellations, but the earliest systematic list that has come down to us is referred by him to 1000 B.C. This so closely resembles Ptolemy's list as to leave little doubt that the constellations adopted in the West had their origin in the East.

There is a similar division into three groups, northern, central, and southern ; the Babylonians dedicated these to the gods Enlil, Anu, and Ea respectively ; the numbers of constellations in the three groups are thirty-three, twenty-three, and fifteen respectively ; the middle group comprises twelve equatorial ones, and eleven adjacent to these. Ptolemy's numbers are twenty-one, twelve, and fifteen ; the difference of numbers merely means that separate names were given to parts of constellations, much as we now divide Argo into four parts.

A few of the Sumerian names may be mentioned. Perseus and Andromeda are Sugi and Lulim. Arcturus, Sirius and Spica are Supa, Kaksidi and Absim (the latter is described as " an ear of corn "). Castor and Pollux are Mastabba Galgal, the Great Twins. Dilgan is not Capella, as some people thought, but is a group of stars in the Waterman, near the Whale ; the mistake arose from assuming that the Sumerians began their year near the equinox, whereas they began, as we do, about the winter solstice. Mul-mul (meaning the " Seven great gods ") is the Pleiades.



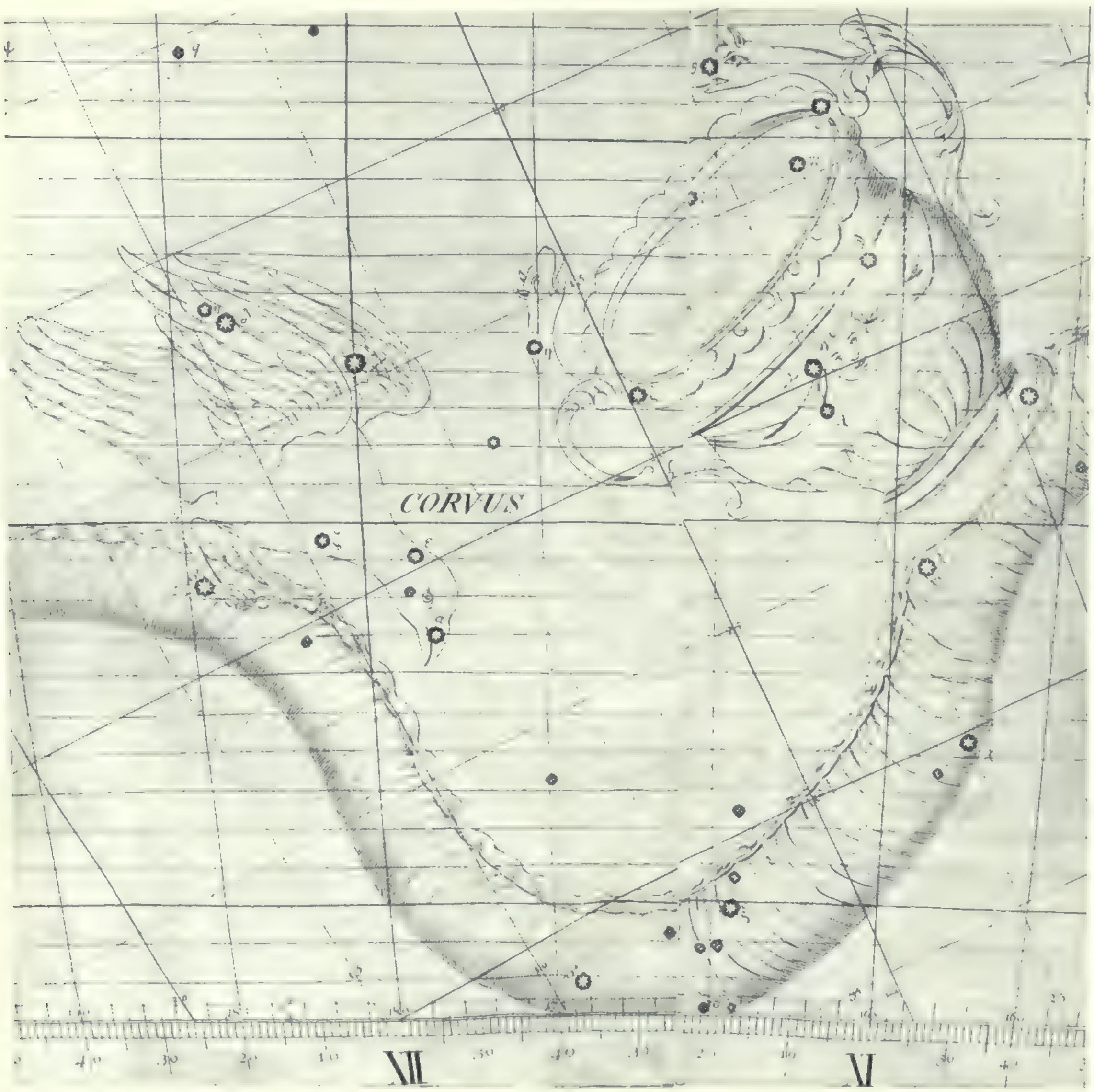
ERIDANUS, THE RIVER PO.
This is a very long constellation, winding between Orion and the Whale. It has been gradually extended farther south, as precession brought new stars into view. It is conjectured that the River depicted may originally have been the Nile, a much more famous stream than the Po.

The Lion is Urgula (Kugler states that the literal meaning is " Big Dog," but a lion was evidently intended). As in Ptolemy, the constellation later called Libra is known as the Claws of the Scorpion. Our Great and Little Bears are two waggons, Margidda and Margidda anna. " The star that stands in the pole of Margidda anna is the son of the goddess Ninmah, the firstborn of the god Anu." This refers to the pole star of that epoch, presumably Beta of the Little Bear, which was six and a half degrees from the pole in 1000 B.C. The Lyre is Uza, its chief star Vega is Nibu. The Dolphin is Sahu, the Pig (compare the German Meerschwein). Hydra, the Raven and the Eagle are called by Babylonian names that are synonymous with the Greek ones, but the Swan and Pegasus are grouped together as the Panther ; while the name Sisu, Horse, is given only to the Little Horse, Equuleus.

The Wolf, the Centaur and Argo appear under the names Ur-Be (" The Mad Dog," not a very acceptable victim for the Altar), Entena massig and Nunki. No hint is given by Kugler as to how the Centaur was pictured. Allen states that it was given the figure of a bull, instead of the man-horse

combination. The Southern Cross is entitled Gan-Gusur, "The weapon of the god Amal." Alpha and Beta Centauri are named Lugal, "King," and Pa.

Kugler identified the Babylonian constellations by putting together a large number of statements about stars that rose and set together, and about the angular distances between certain stars ; a great deal of labour was involved, but the results appear to be practically free from doubt. One interesting



HYDRA (THE WATER-SNAKE), CRATER (THE CUP), CORVUS (THE RAVEN).
Hydra is a very long constellation, and formerly marked the celestial Equator. Corvus, the Raven, is supposed to be the bird associated with the Deluge narrative. It is plucking at the flesh of Hydra, symbolising the disappearance of the Deluge water. The Arabic name for the Cup is Al Kas (Hebrew Kos, a Cup). The brightest star is called Alkes, a corruption of this word.

fact may be mentioned. From the beginning of the first Babylonian dynasty (about 2000 B.C.) the first month, called Nisan, began with the heliacal rising of Aldebaran ; this occurred on the average thirty-six days after the equinox. The changing date of New Moon would cause an oscillation of a fortnight each way. Some 1,300 years later Hamal, the chief star of the Ram, was substituted for Aldebaran.

ORION AND THE HARE.

Almost all nations have seen the form of a giant, either Hunter or Warrior, in this star-group. The Chinese arm him with a hatchet instead of a Sword and Club. The Belt is marked by three bright stars; it is close to the celestial Equator. Betelgeuse is in the right shoulder, Rigel in the left foot. His attention seems to be divided between the Hare and the Bull, that with lowered horns resists his onslaught. The legs of Monoceros (the Unicorn) and of the Big Dog, are seen on the left; the winding river Eridanus on the right.

In Sumerian times, about 2700 B.C., the year began about our January or February. The fifth month was called Antasurra, the name being stated to have reference to falling stars; Kugler conjectures that these may have been the Perseid meteors, which then came about two months earlier in the year than they do now, owing to perturbations of the orbit and precession.

Kugler prints an early Babylonian document containing what he regards as the first hint of the "Stations of the Moon" that were adopted later. These stations are simply a division of the Zodiac into twenty-eight or sometimes twenty-seven portions, corresponding to the daily journey of the Moon; this arrangement was made independently in China, India, and Arabia. Kugler notes that the twenty-eight Nakshatra in the Indian Veda begin, like the Babylonian list, with the Pleiades; the latter list runs thus: Pleiades, Hyades, Orion, Perseus, Charioteer, Twins, Crab, Lion, Virgin, Claws, Scorpion, Archer, Goat, Southern Fish, west part of Waterman, east part (Dilgan), Fishes, Ram. (Total 18.) This is simply the twelve zodiacal constellations with a few additions, and needs much alteration to make it a set of Moon-Stations.

I pass on now to describe the Biblical allusions to the constellations. There are first some associations between the signs of the Zodiac and the Twelve Tribes. Josephus says of the twelve stones in the high priest's breastplate, "Whether we understand by them the months, or the signs of that circle which the Greeks call the Zodiac, we shall not be mistaken in their meaning." In Joseph's dream the Sun, Moon and eleven stars, or constellations, bowed down to him. The badge of the tribe of Joseph (or Ephraim) was a Bull, which at that time was the leading zodiacal sign. The eleven would be the remaining signs.

From Saussure: "L'Astronomie Chinoise."

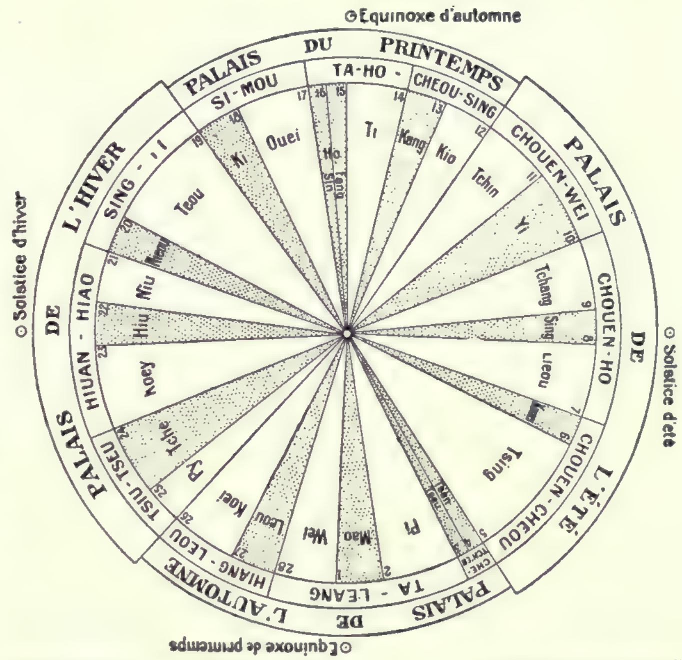
THE TWELVE SIGNS OF THE CHINESE ZODIAC.

The Chinese signs are quite independent of those used in the West. They are the Dog (our Ram), the Cock (our Bull), the Ape (our Twins), the Ram (our Crab), the Horse (our Lion), the Serpent (our Virgin), the Dragon (our Scales), the Hare (our Scorpion), the Tiger (our Archer), the Bull (our Goat), the Rat (our Waterman), the Pig (our Fishes). Six are tame, and six wild. The numbers round the circle show the Lunar Mansions contained in each Sign.

In Numbers ii. there is reference to the standards of four of the tribes: that of Judah on the East, of Reuben on the South, of Ephraim on the West, of Dan on the North. Tradition gives as the badges of these four standards a Lion, a Man and a River, a Bull, an Eagle and a Serpent. Genesis xlix. shows the appropriateness of at least three of these. Verse 9, "Judah is a lion's whelp" (*compare* Apoc. v. 5, "The Lion of the tribe of Judah"). Verse 4, "Thou (Reuben) art poured out as water." There is no direct allusion to the Bull, the third emblem; but in verse 22, "The daughters run upon the wall,"; Mr. Maunder notes that the word for wall is Shur, which differs only by a vowel point from the word for Bull, which is Shor. The vowel points were not added till centuries after the consonantal text was written. If we take the reading as Bull, the "daughters" would be the Pleiades on its shoulder.

As regards the eagle and serpent, Dan is referred to in verse 17 as "A snake in the way, a serpent in the path that biteth the horse's heels." We have in close proximity to each other in the sky the Eagle, the Serpent-Bearer, and the Scorpion biting his heels. It will be noted that at the date in question the Lion and the Waterman marked the summer and winter solstices, while the Bull and Scorpion marked the Spring and autumn equinoxes.

We obtain, as Mr. Maunder points out, some confirmation of the traditional emblems on the standards by the words of Balaam as he looked down on the Israelite host (Numbers xxiii. 22), "His strength is like to the wild ox" (Hebrew, Reem). Again (verse 24), "The people shall . . . lift itself up as a lion." Again (xxiv. 7), "Water shall flow out of his bucket."



From Saussure.] [" L'Astronomie Chinoise."

THE TWENTY-EIGHT CHINESE LUNAR MANSIONS.

The picture shows the arrangement of the twenty-eight Sieou, or Lunar Mansions. Note the palaces of the four seasons, Printemps being Spring, Eté Summer, Hiver Winter. The central sign of each palace contains three Sieou, the others contain two. The first Sieou, Mao the Pleiades, comes in the Autumn palace, since the Full Moon is here at the autumnal equinox. Tseu and Tsan are in Orion, Sing is Alphard in Hydra, Kio is Spica, Sin is the Dragon's Heart (Antares). Each Sieou is a triangle with its apex at the pole of the equator. They were used in the Chinese cometary observations.

The four living creatures, Man, Lion, Ox, Eagle, occur again in the Vision of Ezekiel (i. 5 to 14). They are again mentioned in Apoc. iv. 7, and were afterwards taken as emblems of the four Evangelists; thus, for example, we have the winged lion of St. Mark at Venice.

We also find the Signs of the Zodiac referred to collectively in two passages: first passage, Job xxxviii. 32, "Canst thou bring forth Mazzaroth in their season?" second passage, 4 Kings xxiii. 5 "Them also that burnt incense to the Sun, and to the Moon, and to the Mazzaloth, and to all the host of heaven." Before the decipherment of cuneiform inscriptions, there was considerable doubt about the meaning of the terms Mazzaroth and Mazzaloth. But the position is now different; the word Misrata occurs in the Babylonian Creation Epic in context which leaves no doubt that it refers to the division of the Zodiac into twelve parts; a further subdivision of each into three sections is hinted at. The verb masaru means to divide (L. W. King); this only differs from the root letters of Mazzaroth by the substitution of the letter Tsade for Zayin. We may therefore confidently adopt "The signs of the Zodiac" as the meaning of Mazzaroth. The bringing them forth in their season would refer to the regular succession in which they appeared in the course of the year, after being veiled by the presence of the Sun.

Mazzaloth may be merely a variant for Mazzaroth; there is, however, an appropriate Assyrian word in this case, Manzaltu, "Station," from the root Nazazu to stand; so that the reference may be to the Zodiac as divided into the twenty-eight "stations of the Moon" instead of the twelve solar signs.

There are several Hebrew constellation names in the Old Testament, whose identification has been the occasion of much discussion: Job ix. 9, "Who maketh Ash, Kesil, and Kimah, and the chambers of the south;" Job xxxviii. 31, "Canst thou bind the chains (or, sweet influences) of Kimah, or loose the bands of Kesil." Verse 32 mentions Mazzaroth, and also Ayish, which is probably the same as

CHINESE CELESTIAL GLOBE.

Ko Show-King made a celestial globe, turning by machinery, that showed the equator, ecliptic and principal star groups. The globe in the picture is more modern, but probably similar in design.

Ash. Amos v. 8 again mentions Kimah and Kesil. There is little dispute now about these two; they are taken to be the Pleiades and Orion respectively; Kimah appears to mean a collection or cluster, like the Assyrian Kimu or kimtu, "family." If the translation "sweet influences" is correct, it would refer to the beauties of Spring that open out when the Sun passes the cluster. Kesil means a fool or impious person. Tradition connects the giant hunter in the sky with Nimrod (Genesis x. 8) conjectured to be Merodach (more correctly spelt Marduk). Gibbor is the Hebrew for a giant or mighty man (the root occurs in the name Gabriel) and Orion has long been called Algebar or Gabbara the Giant; Longfellow's poem, "The occultation of Orion," regards him as the embodiment of lawless violence; this tradition seems to accord well with the designation Kesil. Mr. Maunder notes that he is portrayed in the heavens as trampling on the timid hare, and trying to climb into the Zodiac, being prevented by the determined attitude of the guardian Bull. It has been pointed out that the name of the month Kislev (approximately our December) contains the same root letters as Kesil; it is the month when Orion is best placed for observation, shining throughout the night. There may therefore be a connection between the names.

The identification of Ash or Ayish is less certain; there are two rival views that are both plausible. Schiaparelli favoured Aldebaran and the Hyades, noting that early Syriac translations use Iyutha for Ash, and Iyutha almost certainly refers to this stellar group. Also Ash means a moth, and the Hyades resemble a moth with its wings folded.

Others favour the view that Ash is the Great Bear, noting that the Arabs call the four bright stars in the body of the Plough by the name na'sh, "the bier"; we still call the star at the end of the handle Benetnasch, "daughters of the bier."

As to the "Chambers of the South" in Job ix. 9 we can only conclude that they refer to some of the brilliant constellations that were seen near the southern horizon; the fine group formed by Argo, Centaurus and the Southern Cross has been suggested.

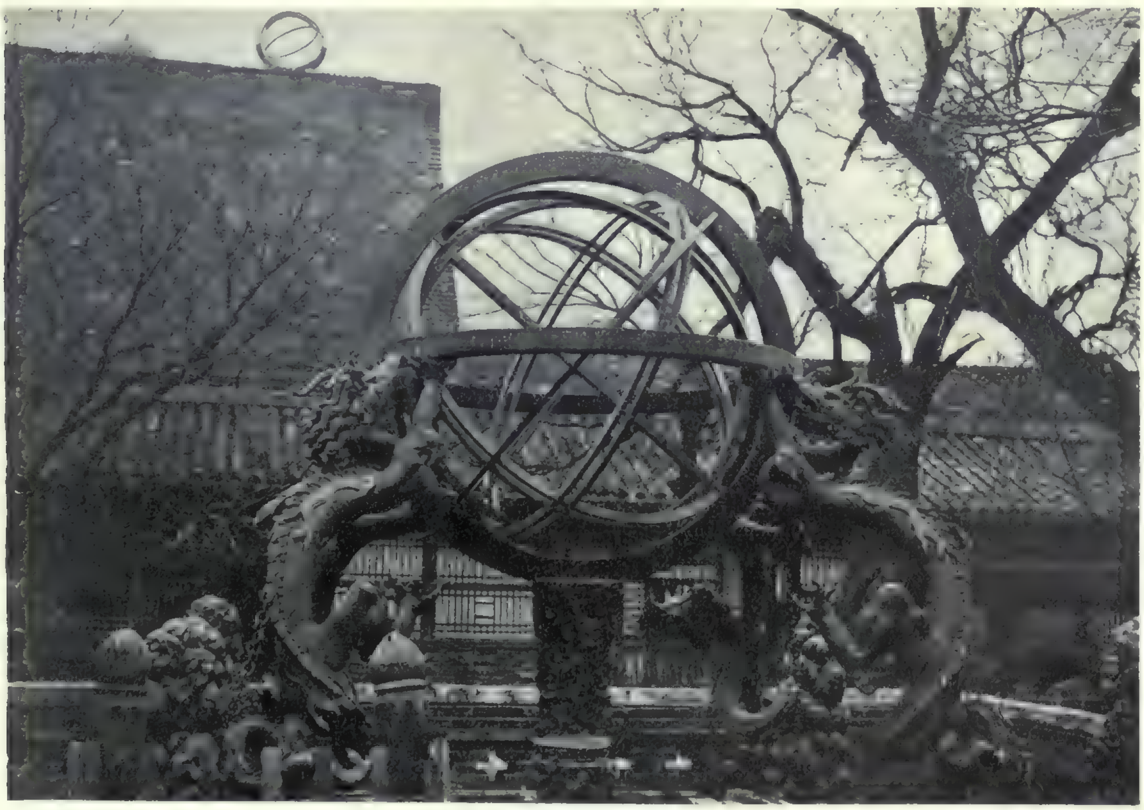
South and North are placed in antithesis in Job xxxvii. 9. The word for north is mezarim, "scatterings." Schiaparelli noted that with a change in the vowel points this would make mizrayim, "the

two winnowing fans" ; he thinks that this may denote the chief stars of the Great and Little Bears, whose outlines are quite suggestive of winnowing fans.

We have ourselves alternative names for the seven bright stars in the Great Bear, using the names "Plough" and "Charles' Wain," while the Americans call them the "Big Dipper" ; it is therefore not unlikely that in old times they had more than one name. There are two passages (Job xxvi. 12, 13, and Isaiah xxvii. 1) that refer to some of the serpentine constellations. The former passage is shown to have an astronomical bearing by the "adorning of the heavens" in the first half of the verse. The Hebrew "nahash bariah" has been variously rendered "crooked, winding, swift, or gliding serpent," but "fugitive serpent" seems to accord best with the root meaning of the word. This phrase would accord with the serpent that is in the grasp of Ophiuchus, and endeavouring to escape.

"Nahash bariah" occurs again in Isaiah xxvii. 1, and is followed by "nahash aqallathon," "the crooked serpent," which is almost certainly our Dragon ; its tortuous windings are shown on page 649. The passage continues with "the whale (Heb. tannin) that is in the sea." This is probably our Cetus, the whale. Job xxvi. 12, refers to Rahab, "the proud." Mr. Maunder sees here another reference to "the whale," the Septuagint reading Ketos.

We find the Dragon mentioned again in Apocalypse xii. We have already alluded (page 238) to the possibility that the great dragon "whose tail drew the third part of the stars of heaven and cast them to the Earth" may have a reference to the departure of the Dragon from the place of honour at the top of the celestial sphere. Mr. Maunder notes that the subsequent verses, "And the serpent cast



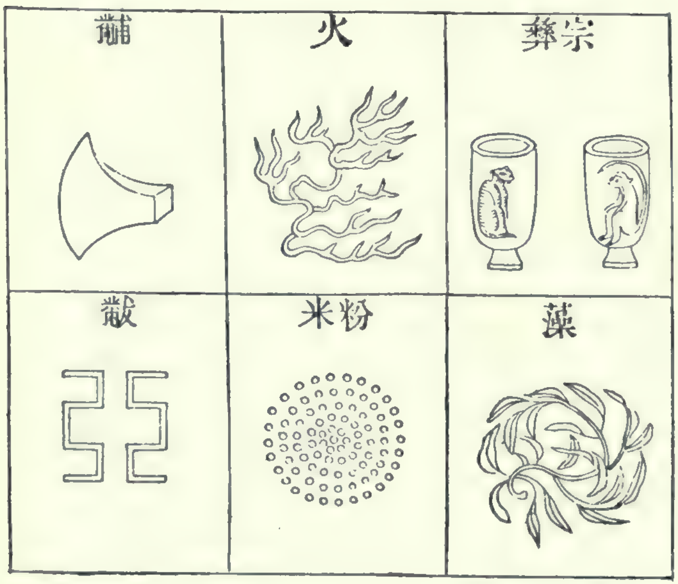
CHINESE ARMILLARY SPHERE.

This large instrument was erected by Ko Show-King, official astronomer under Kubla Khan, about A.D. 1276. It replaced an older instrument made about 1050. It will be seen that it turns about a polar axis, and has circles corresponding to the horizon, equator, ecliptic and several meridians. One of the latter carried a tube, movable about the centre of the sphere, for pointing to a heavenly body. The circles are some six feet in diameter, and are graduated in Chinese degrees, 365¼ to the circumference.

out of his mouth . . . water as a river . . . and the Earth opened her mouth and swallowed up the river which the dragon cast out of his mouth," agree closely with the configuration of Cetus and Eridanus (*see* pages 658 and 659). The River Eridanus flows just in front of Cetus, and extends down to the southern horizon, where it appears to be swallowed up by the Earth. The chapter begins with the words, "A great sign appeared in heaven," which lends support to the view that the imagery is derived from the constellation figures.

We may note that the Scripture writers, while adopting the constellation figures of the Babylonians, did not follow them in their childish myths concerning their origin. A much nobler view of the real significance of the wonderful celestial pageant is expressed in the fine passage in Job xxvi. 14, "Lo these things are part of His ways, but how little a portion do we hear of Him. The thunder of His power who can understand ? "

The ancient Chinese Zodiac is quite independent of that in use in the West ; it has varied at different times, but the following appears to be the original arrangement :—



From Saussure. *"L'Astronomie Chinoise."*

CHINESE CELESTIAL EMBLEMS.

The designs here shown are the Ancestral Cups, with Apes (a Zodiacal constellation) upon them : the Aquatic plant (identified with Laurus Cassia) : Fire (emblem of summer) : Rice grains, symbolical of the harvest, and of the fertility produced by the Sun : The Hatchet, the weapon of The Warrior (Orion) ; and the Double Zig-Zag.

Chinese.	Western.
Dog	Ram.
Cock	Bull.
Ape	Twins.
Ram	Crab.
Horse	Lion.
Serpent	Virgin.
Dragon	Scales.
Hare	Scorpion.
Tiger	Archer.
Bull	Goat.
Rat	Waterman.
Pig	Fishes.

For the last three or four centuries the Chinese have adopted a zodiac practically identical with that in use in the West.

The Chinese appear to have used the lunar mansions or Sieou to a greater extent than the twelve signs. These were twenty-eight in number, and were based on the celestial equator, not on the ecliptic. Each mansion was a triangular patch of the heavens extending up to the north pole, so that a statement that a heavenly body was in a particular mansion gives no information as to its distance from the equator. Several of the cometary observations are of this character, and it is less easy to utilise them than if a reference were given to the actual stars near the comet.

Each Sieou is called after some star or group of stars. Thus Mao is the Pleiades, Tseu and Tsan are respectively the head and belt of Orion, Sing is Alpha Hydrae, Kio is Spica, Fang is a group in the Scorpion. It will be noticed that the mansions are very unequal in size.

They are divided into four groups or palaces, seven in each palace. These correspond with our four seasons. The reason of the inequality in size of the mansions is to make them fit accurately into the twelve zodiacal signs ; the middle sign of each palace contains three mansions, which are therefore small, while the two outer signs contain two mansions apiece. The spring palace is called Tsing Lung, the Green Dragon (its centre constellation is our Scorpion) ; the summer palace is Choo Neaou, the

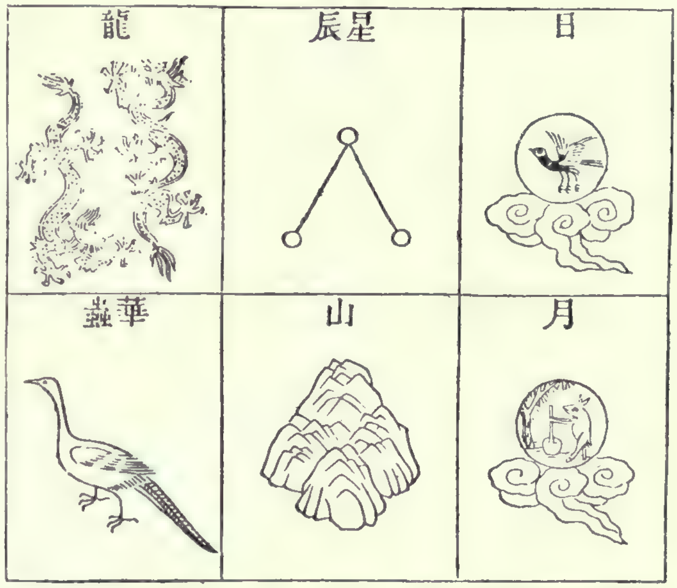
Red Quail ; its centre is marked by the Quail-Fire, or Heart of the Quail (our Alpha Hydrae, or Alphard) ; the autumn palace is Pih Hoo, the White Tiger (its centre is our Orion) ; the winter palace is Heung Woo, the Black Tortoise. It is easy to see the appropriateness of associating Green with Spring, Red with the fiery heat of Summer, Black with the gloom of winter. The palaces were also associated with the substances that the Chinese looked on as elements : Wood with Spring, Fire with Summer, Metal with Autumn, Water with Winter, Earth in the centre of all. The Chinese gave the following poetical reason for this association :—

Wood prevails over Earth by absorbing it:
Metal prevails over Wood by cutting it:
Fire prevails over Metal by melting it:
Water prevails over Fire by quenching it:
Earth prevails over Water by absorbing it.

The annual cycle of seasonal changes is thus symbolised.

The lunar mansions begin with the region associated with the autumnal equinox, not with the spring one, like the zodiacal signs. The reason is that they are associated with the Full Moon, which is always opposite to the Sun. The symmetry of arrangement of the mansions made it easy to infer the position of the Sun by noting the place of Full Moon and taking the opposite mansion.

The intimate association that the Chinese imagined to exist between the terrestrial and celestial regions was mentioned in the chapter on comets ; an interesting example is given by Père Gaubil. He states that two faint stars in the Dragon, that were the pole stars of the twenty-seventh and twenty-third centuries B.C. respectively, were named " The unique of the Heavens " and " The unique Supreme." These celestial titles are closely analogous to that of the Emperor of China, who was called " The unique man." If the stars have been correctly identified by Gaubil, their detection as pole stars reflects great credit on the early observers : for the star Thuban in the Dragon was much brighter, and not far from the pole (*see* page 228).



From Saussure.] [" *L'Astronomie Chinoise.*"

CHINESE CELESTIAL EMBLEMS.

The designs are reproduced from a Chinese work of A.D. 1730, but are supposed to be copied from older originals. They are : The Cock (a zodiacal constellation, and a symbol of the Sun) ; The Hare (a zodiacal constellation, and a symbol of the Moon, it is pounding drugs in a mortar). The Star-group, The Mountain, The Dragons (a zodiacal constellation), The Pheasant (a constellation).

A few of the Chinese names of stars and constellations may be given. The seven bright stars of the Great Bear were Pih Tow, the Chariot. The northern of the pointers was Choo, the feet of the Bear San Tae. Arcturus was Ta Kio, the Great Horn. Vega, with some neighbouring stars, was Chih Neu, the Spinning Damsel. Castor and Pollux were Ho Shoo, or Pih Ho. The Milky Way was Teen Han or Tien Ho, the Celestial River. The region round the pole, that never set, was Tsze Kung or Tsze Wei Yuen.

I am indebted for the above to Williams, " Chinese Comets," R. H. Allen, " Star Names," and Saussure, " Les Origines de l'Astronomie Chinoise."

Some mediaeval Chinese astronomical instruments are depicted on pages 640, 664, 665; these are

probably of similar design to those used in very ancient times. It is clear that China was one of the leading nations of antiquity in astronomical study. But it was isolated from other nations, so that the discoveries made in it did not reach them, and they had to find them independently. India is an exception; Saussure proves that many points in its ancient Astronomy show traces of Chinese influence.

It remains to say something about the Arabic star-names. The fact that so many of these have been universally adopted is testimony to the zeal of the Arabians and their assiduity in study not merely of the constellations as a whole but of the individual stars. This was doubtless partly inspired by their utility as guides for travelling at night across the trackless deserts. Indeed, there is little doubt that among all the ancient nations star-knowledge was far more widely diffused than it is to-day. Before the introduction of clocks and watches they afforded the only method of measuring the progress of the night. We find a character in Euripides asking " What is the star now passing ? " The reply, " The Pleiades show themselves in the East, the Eagle soars in the summit of heaven," conveys all the information he desires. Study of the monthly star-maps in this work will enable our readers to place themselves on a level with those old observers.

From " The Heavens and their Story " By A. & W. Maunder.
By kind permission of the Epworth Press.] *[Photograph by F. W. Longbottom.*

THE STARS OF THE PLOUGH.

The photograph shows the seven bright stars of the Plough, part of the Great Bear. Dubhe means Bear (Hebrew, Dobh), Merak Loin, Phecda Thigh, Megrez Root of Tail, Alioth Tail (doubtful), Mizar Girdle, Benetnasch Daughters of the Bier. Hence the Hebrew Ash is concluded to be the Plough. The meaning of Alcor is doubtful; another Arabic name for it was Suha, the lost or neglected one.

The Arabic names are in many cases almost identical with words in Old Testament Hebrew; there are some words that occur in several star names, so it is useful to give them: Ras, a head (Hebrew, Rosh); Rijl or Rigel, a foot (Hebrew, Regel); Deneb or Danab, a tail (Hebrew, Zanab); Al is simply the definite article "the." Janubiyyah, corrupted into Genubi, means " southern "; Shamaliyyah, corrupted into Chamali, means "northern." These latter names occur in the Scorpion's Claws, now Alpha and Beta of the Scales. Most of the stars down to the third magnitude, and some still fainter, possess Arabic names: it must suffice here to give the meanings of those of a few of the brighter stars. Betelgeuse in Orion is a corruption of Ibt al Jauzah, " the armpit of the central one."

Vega, in the Lyre, is from the Arabic Waki; this star was sometimes called the Falling Eagle, while Altair in Aquila is a contraction of Al Nasr al Tair, the Flying Eagle (the Hebrew for an eagle is Nesher). The star that we now call Polaris had the Arabic name Al Rukkabah, the Chariot or Charioteer, (Hebrew, Rekub).

The seven bright stars in the Plough have all Arabic names (*see* figure on this page). Dubhe means " bear " (Hebrew, Dob), Merak " the loins," Mizar " the girdle," Benetnasch " the daughters of the bier."

Achernar "the last of the river" (Hebrew, Ahar after, nahar river) is at present the end of the long River Eridanus. In Ptolemy's time the river ended with Theta Eridani.

The Arabs used the Greek names (slightly modified) of three constellations: Al Thaur, Taurus; Al Kentaurus, the Centaur; Al Ketus or Kaitos, the Whale. Thus Zeta Ceti is Baten Kaitos, the whale's belly (Hebrew, Beten). It is curious that there is no generally accepted proper name for Alpha Centauri, our near stellar neighbour. Ulug Beg called it Al Rijl al Kentaurus, the Centaur's foot; this name would be liable to confusion with Rigel in Orion. The old Sumerian name Lugal, "King," might be revived. Dr. Innes suggested the name Proxima, but he has since transferred this name to a faint star, in the same region of the sky, that is nearer to us than the bright star (*see* page **466**).

I recommend those readers who wish to pursue further the very interesting study of star names to consult "Star names and their meanings," by R. H. Allen. Some readers may be disposed to think that this chapter deals more with men's fancies about the heavens than with the heavens themselves. This is true in a measure: nevertheless, I think that the early progress of astronomical knowledge is worthy of the minutest study on the part of all devotees of the science. Contempt for these pioneers is quite a misplaced sentiment. The great advance that has been made in modern times was rendered possible by the patient labours of our predecessors. The numerous problems that the heavens present cannot all be solved simultaneously. Each fact that is wrested from nature brings new problems in its train, but gives us increased power to deal with them. Three examples may be given of the indebtedness of the new Astronomy to the old. (1) Kepler in deducing his laws of planetary motion required accurate values of the periods of revolution; these were available, thanks to the work of observers centuries earlier. (2) Our knowledge of the acceleration of the Moon's motion is derived from eclipses recorded in Assyria, Greece, etc., two or three thousand years ago. (3) The possibility of tracing back the history of Halley's Comet for over two thousand years is due almost entirely to the careful star-watches of the Chinese: it involved a study of their constellation figures, and indeed of the whole of their system of recording astronomical phenomena.

From "Astronomy of Bible."] [*E. W. Maunder*

THE ANCIENT CONSTELLATIONS SOUTH OF THE ECLIPTIC.

The picture shows the more or less circular gap in the old constellations, also the path of the south pole due to precession. About 2700 B.C. the pole was central in the gap. From the size of the gap we infer that the constellation-designers lived about latitude 37° north.

Far from despising the pioneers, we should respect them; the foundation is the most important part of an edifice, and the foundation stone of the lofty structure of astronomical science was well and truly laid in the distant past.

CHAPTER XVIII.

RELATIVITY AND GRAVITATION.

By Herbert Dingle, B.Sc., F.R.A.S.

A NEW idea in Science cannot long remain by itself. It is like a handful of seeds blown abroad into alien fields of philosophy, ethics, theology, and practical affairs, and taking root there, slowly or quickly according to the nature of the idea and of the soil. To the man of science it still remains a scientific idea: he is less concerned with the offshoots than with the parent seed. But to the great majority of people, who have had no specialised training in science and whose outlook is, as a rule, less scientific than personal or artistic, the offshoots are all that matters: the science at the root is a hidden thing, and it is only by its fruits that it is known. Of all the great departments of human thought, science is perhaps the most specialised, the most given over to its regular workers, and it is a natural consequence that until the progress of science makes itself felt in other activities of the mind, it remains for the most part unknown or is not understood. The principle of relativity is slow to take root in the more populous fields: it is for that reason, more than for its inherent difficulty as a scientific conception, that it has acquired its widespread reputation for unintelligibility.

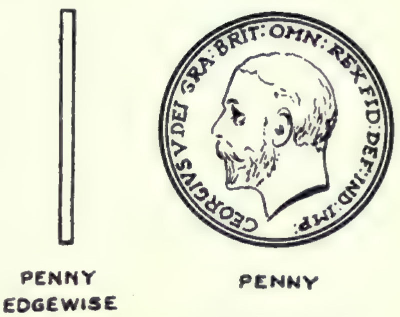
Photo by W. Benington] *From "The Sphere," by kind permission of the Editor.*

PROFESSOR ALBERT EINSTEIN AND LORD HALDANE.

Professor Einstein, the famous author of the principle of relativity, visited England in June, 1921, when he was the guest of Lord Haldane. He has made important contributions to other branches of physics, notably the theory of photo-electricity. Lord Haldane, who has himself written on the philosophy of relativity, is keenly interested in Science, and was the first President of the British Science Guild.

It was quite otherwise with the idea of evolution, for example. In itself essentially and entirely a scientific theory, the idea of evolution had an obvious and immediate bearing on theology, and for

one person who found it difficult to understand there were a thousand who found it impossible to accept. This was not due to its simplicity: indeed, it is very questionable how many of the thousand understood the conception which they resisted. The familiar tag, "men came from monkeys," was a sufficient explanation for the majority, who seemed to think they had secured a complete grasp of the whole of Darwinism in that preposterous phrase. An example of another kind is to be found in Clerk-Maxwell's equations of the electro-magnetic field. It was not so very long before Hertz found the waves which Maxwell predicted, and Lodge, Marconi and others gave us wireless telegraphy. To-day, millions are familiar with the magic words: "Hullo, everybody; London calling"; thousands make receiving sets, erect aerials, and enjoy the fruits of scientific research; but how many understand the underlying idea, which was at first a speculative hypothesis and is now essentially an abstract physical theory? We do not hear Clerk-Maxwell's theory, or the intrinsically still less intelligible notions of Faraday, which preceded it, characterised as difficult or mysterious—not because they are not so, but because they have blossomed into practical use, and the blossom is visible to all. It is probably safe to say that if the principle of relativity had shown itself at once to have an application in the more popular regions of thought or action, it would never have been branded with the stigma from which it now suffers.



A PENNY FROM DIFFERENT POINTS OF VIEW.

The appearance of a penny depends on the point of view of the observer, yet the conception of a penny as a three-dimensional object reconciles observations from all points of view.

If, therefore, we are to give an exposition of relativity that will enlighten and not mystify the general reader, we must attempt, however imperfectly, to show how some old and more or less familiar problem takes on a new aspect in the light of this great scientific generalisation. It is not to be expected that our presentation will more than adumbrate the ultimate view of the problem—the light is yet too dazzling to permit of clear, steady vision—but, such as it is, we may claim for it that it is true, and we may trust also that it will be not more difficult to comprehend than many other ideas which the human mind has in the past accepted and made part of its conception of Nature. We will try in this chapter to show how the principle of relativity affects our most general view of the world, and gives to philosophy—the ordinary philosophy of the ordinary man—an outlook consistent with that which science must in the future adopt.

Photo by] [*Elliott & Fry.*

PROFESSOR A. S. EDDINGTON, F.R.S.

Professor Eddington, Plumian Professor of Astronomy in the University of Cambridge, is not only the leading English exponent of Einstein's Theory of Relativity, but has also contributed considerably to the development of the subject.

One of the best-known and most-discussed problems of philosophy is this: Has the external world, which we apprehend by means of our five senses, an independent existence, or is it fashioned out of the substance of our own minds? Is it an objective reality, or a subjective illusion called into existence by our tendency to assign a cause to the sensations which we experience and which, strictly speaking, are all that we have direct knowledge of? In brief, is there an external world, or is there not? By external world we mean primarily matter.

The familiar objects of our daily life—trees, houses, mountains, stars—these are the external world, distributed in a boundless space and remaining unchanged in quantity as the passage of the years brings us into being and takes us on through old age to death and beyond. Does this so solid seeming world exist in itself, or does it not ?

Science has never faced this question, which it has regarded as lying outside its scope. It has studied the external world just as if it were a reality, without concerning itself with the metaphysical challenge thrown out to it. It has assumed the existence of material bodies, and studied their properties in time and space. And it has been justified in so doing, because the external world, real or supposititious, has always seemed to be the same to everybody. What one person calls an apple, another calls an apple ; if one sees the apple fall, another, if he is looking, also sees it fall. These things being so, it matters not at all, so far as the properties and distribution of apples are concerned, whether their existence is real or imaginary : they are the same to everybody, and that has been a complete justification for Science.

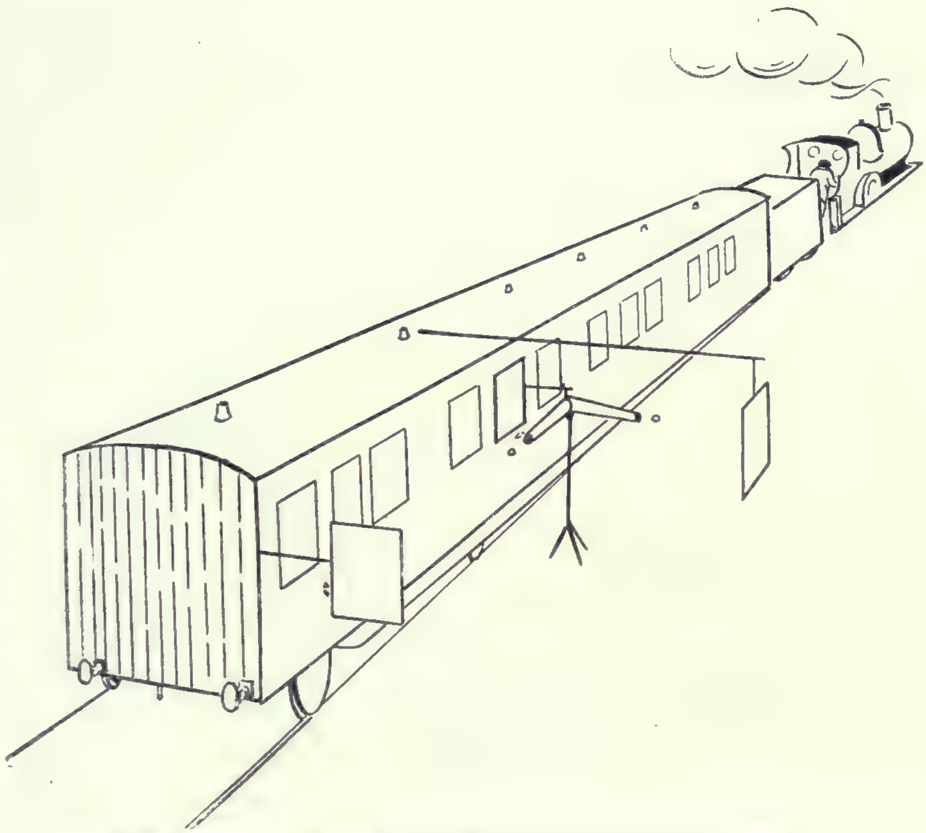
[By Theo. Carreras.

A MIRAGE.

Objects are sometimes seen in the sky by certain persons, and not by others having different points of view. The appearance is explained by assuming an abnormal distribution of density at a certain level in the air, which gives rise to a refracted image of objects existing elsewhere on the Earth's surface.

There have always, of course, been a few exceptions to the rule. Occasionally one arises to whom things are different from what they are to the majority. Thus, Lear saw his daughter, Goneril, where others saw a joint-stool. Cases of this kind, however, have given very little difficulty to Science : the exceptional people have been called "mad" and shut up in an asylum. In their existence there has been seen no denial of the consistency of postulating an external world : on the contrary, they are said to have "lost their senses," to have no power of apprehending the things that exist outside them. The same anomaly, and the same explanation, occur in the delirium of a few and the dreams of all ; but here the challenge to Science is still less potent, for these things are temporary, and the sufferers themselves, on recovery, are willing to acknowledge that they have been deluded. Again, there are some people to whom, for

example, two objects, ordinarily called " red " and " green," respectively, appear to have exactly the same colour. These people also are assumed to be deficient in certain organs of sense: they are termed " colour-blind," and their peculiarities are disregarded in the scientific formulation of the properties of things. And there are the experiences of the saint and the ascetic, the apprehension by a few of material things unperceived by the majority. Experiences of this kind likewise are attributed to the abnormal state of the percipient, and not to vagaries in inanimate objects. It has always been possible, on more or less plausible grounds, to assign departures from the ordinary view of things to the extraordinary state of the observer, and it has therefore been possible for Science to maintain her supposition that there is an external world.



THE PRINCIPLE OF THE MICHELSON-MORLEY EXPERIMENT.
A traveller in a train could measure his rate of movement by firing stationary guns at plates fixed to the train in the manner shown in the figure, and noting the interval between the return of the shots. The practical difficulties of the experiment are, of course, insuperable, but the principle is sound.

It must be understood that this universal agreement of normal people with regard to the objects of perception is absolutely vital to Science. Unless it exists, in every detail, without the slightest exception, there is an end of Science as a form of Truth. She may still, of course, continue, and indeed be indispensable to civilisation; no undermining of the philosophical justification of Science can alter the fact that she has given us aeroplanes and wireless telegraphy and surgery, and whatever her status may be, she will doubtless go on changing the direction of our mortal activities. But if, even in the veriest trifle, one person were to perceive an object differently from other people, in such a manner that the difference could not possibly be ascribed to a mental or physical peculiarity of that person, Science would no longer be a goddess to be worshipped; she would become a handmaiden to be trained and used. It is the identity of our conceptions of the world that is the real law and order which we often hear it said that Science has demonstrated. Law and order are not revealed by the derivation of a mathematical formula expressing the course of events, and they are not verified by the successful prediction of a future event, such as a solar eclipse. *Any* conceivable succession of measurable events, whether it actually occurs or not, can be represented by a formula —by an infinite number of formulæ. The success of our predictions merely shows that a sufficiently exact formula is so simple that we have been able to select it out of the infinite number. Law and

order, the intelligibility of the Universe, the regularity of Nature, ultimately lie in the fact that the world presents itself in the same way to every normal person. If that were not so, then not only would there be no law and order in the Universe, but we should not be justified in speaking of the Universe at all; to be in touch with reality we should have to concentrate our attention on our own minds, and abandon the concept of Nature as a complete fiction.

This does not mean, of course, that the world is to be thought of exactly as it appears. On the contrary, the whole progress of Science is a perpetual discovery that things are not what they seem. The stars appear as mere points of light, but we believe them to be globes many millions of times larger than the Earth. A piece of iron appears as a perfectly continuous substance, filling the whole of the space within its boundaries, but we believe it to be an aggregation of millions of molecules, none of which is in actual contact with the others. What we mean by the identity of our individual views of Nature is that everyone's perceptions, when brought into relation with one another, are consistent with a unique conception of Nature. It may be necessary, in order to preserve this consistency, to take into account the point of view of the observer. Thus, a penny to

[L.E.A.

SIR OLIVER LODGE, F.R.S.

Sir Oliver Lodge has devoted many years to the study of the absolute motion of the Earth through space. The failure of his experiments, as of all others, to demonstrate such a motion is a part of the basis of Einstein's theory.

PARALLACTIC MOTIONS OF STARS.

A number of stars appear to describe small ellipses in the sky, once a year. The thickness of the ellipse depends on the angular distance of the star from the ecliptic. It is greatest at the poles of the ecliptic, and becomes nothing at the ecliptic itself. This is taken as evidence that the Earth travels round the Sun (see page 456).

one observer is a circular disc; to another, who looks at the edge of the penny, it is a very narrow rectangle. Both views are consistent with the conception of a penny as a three-dimensional object—a very short cylinder. The penny is not precisely what it appears to either observer, but there is a definition of a penny to which both can agree. That is really what is meant by the statement that the external world is the same for everybody.

We may look upon the aim of Science as the formulation of a conception of the external world which shall reconcile the observations of every normal person. Hitherto it has always been possible to formulate such a conception—hence, as we have seen, the *raison d'être* of Science as a fundamental reality. The achievement has not always been easy; it has meant, time after time, the abandonment of some of our fondest persuasions. A mirage, so far as the senses of the observers are concerned, appears perfectly real, but we must deny its reality in order to

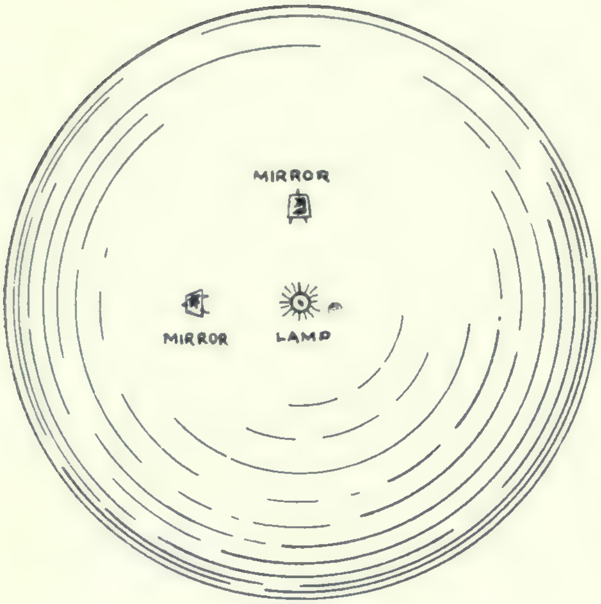
reconcile the observations with those of others having different points of view. Science has found a reconciliation in terms of reflection and refraction of light arising from certain assigned conditions, and the external world is thus made identical for everybody. A passenger enters a train at Victoria and alights some time later at Croydon. If the train, except at starting and stopping, has moved with perfect smoothness and uniformity, and the passenger has been travelling in complete darkness, he has been unconscious of movement. He can say, as justifiably as did the philosophers of the Middle Ages with regard to the Earth, that, except for the initial and final jerking, he has not moved at all. So far as his own immediate experiences are concerned, that is perfectly true. But the geographer comes along and points out that Croydon is ten miles from Victoria, and that, unless the Earth's surface has changed suddenly so that the two places have come together, the traveller must have moved from one to the other. And then the signalman at Streatham Common, who has been on duty throughout the interval, declares that there has been no perceptible Earth-movement and, further, that he has noticed the train travelling along the line towards Croydon. All these observations can be reconciled only by an admission on the part of the traveller that he has been moving without being conscious of movement. He makes the admission, and again the external world is identical for everyone. Science is a continual saving of the world for humanity. It progresses when the world, by modification of our ideas, is saved from the assault of new observations ; it stagnates when the world needs no modification to save it ; it falls when no conceivable modification can reconcile the world to the observations of all.

Photo by [*Russell, London.*

PROFESSOR A. N. WHITEHEAD, F.R.S.

A. N. Whitehead, Professor of Mathematics at the Imperial College of Science and Technology, has shown that Einstein's formulation of the principle of relativity is only one of a number of possible ones. He has re-stated the principle in terms more akin than Einstein's to familiar modes of thought.

Of the various ways in which we adjust our concept of the world to reconcile observations made from different points of view, the most interesting are those concerned with motion. We have just cited one example of this kind of adjustment ; let us extend it a little. Suppose that the traveller still has doubts about the reality of his movement, and decides to repeat his experience, in order that he may apply a test which he has devised. In the circumstances a satisfactory test is not obvious, but he is an ingenious man, and he sets to work in the following way. First of all, he projects a short, straight rod from the window of his carriage, and a flat sheet of stout metal from the back of the train so that its plane is perpendicular to the length of the train. He measures carefully the distance from the rod to the metal plate, and projects a second metal plate, at exactly the same distance from the end of the rod as the first but in a direction perpendicular to the length of the train. The second plate lies opposite his carriage, and faces him as he looks out. Then, somewhere along the line he erects two spring guns, each loaded with an elastic ball and adjusted so that as the train, if it moves, passes them, the rod will just release the springs, thereby ejecting the two balls at the same instant and at exactly the same speed. The guns are fixed so that the first will point, at that instant, towards the plate at the rear of the train, and the second in such a direction that its ball, after it has been ejected, will hit the other plate. Now, supposing that both plates are unyielding and that the balls are perfectly elastic, each ball will be reflected back to the rod. But, if the train is moving,



THE MICHELSON-MORLEY EXPERIMENT.

In the Michelson-Morley experiment, two beams of light were sent out simultaneously in perpendicular directions and reflected back by mirrors fixed to the Earth at equal distances from the source of light. The beams returned together, indicating—contrary to expectation—that the Earth was not moving.

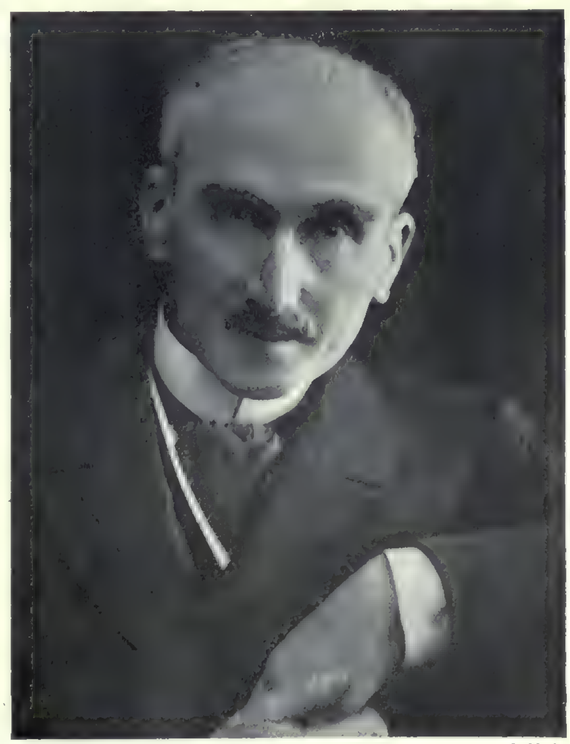
they will not return at the same instant. The ball which has travelled parallel to the train will return first, and the time-interval between the return of the two balls will depend on the speed of the train. The traveller can observe, by the impacts on the rod, when the two balls return, and so find how quickly he is moving. If the balls return at the same moment, then he can conclude that he was not moving at all at the instant when the guns were fired, and then he will have to devise some other explanation of his translation to the position of the guns, or, if that is not possible, he will have to conclude that his own experiences and those of the geographer and the signalman are irreconcilable, and that there is no justification for assuming that the external world, as we have imagined it, exists.

That this is a real test of movement is shown by a very simple calculation. The traveller, according to the universally accepted principles of mathematics, is perfectly correct in his arguments, and, allowing for unavoidable imperfections in imitating the conditions as they have been described, experiments made along these lines come out exactly according to expectations. If the traveller could apply his test exactly as he designed it, he would undoubtedly find that the balls would not arrive back at the same time, and he would find that he was moving at a speed identical with that determined independently by the signalman. The external world, therefore, has stood the test. The traveller must agree that he has been moving. He must recognise that motion does not necessarily make itself known immediately to the one who is moving, and that his failure to experience the sensations which usually accompany movement is no denial of movement itself. A test applied directly to the external world, and not to his own subjective sensations, shows an external world identical with that conceived by others.

We hinted just now at the likeness between the attitude of the traveller before he applied his test and that of the philosophers of the Middle Ages who denied that the Earth was moving because they could feel no movement. The parallel is exact. Instead of the geographer and the signalman we have the astronomer, who says that his observations of the stars and the planets compel him to suppose that the Earth is moving round the Sun once a year; instead of the traveller we have the ordinary Earth-dweller, who cares nothing about the stars and planets but who finds it impossible to believe that he is moving through space at the rate of eighteen and a half miles a second. We have learnt by now to trust the astronomer. We have had so much experience of the deceptive character of our sensations that most of us are willing to assume that if we were to apply a test similar to that devised by our traveller, we should find, just as he did, that we were moving in precisely the way described to us by the astronomer. But the man of Science is ever restive. He cannot let well alone, and no sooner had he conceived a method of applying such a test than he began to put it into operation. Of course he did not question what the result would be, but he wished, as always, to make assurance double sure. The details of the experiment were these. The Earth, of course, represented the train, and its inhabitants the traveller. Instead of the guns shooting elastic balls, there was a lamp shooting beams of light in all directions. Instead of the metal plates there were

two mirrors, which could reflect the light just as the plates were assumed to be able to reflect the balls. The mirrors were fixed to the Earth, just as the plates were fixed to the train, and in every essential point the two experiments were identical. A word should be said about the choice of light as the moving body. Of course it is impossible to fix material guns and balls at some point along the Earth's orbit. All the material bodies over which we have control belong to the Earth and share in its movement. What we want is something which moves with a definite and constant velocity, and which does not partake of the movement of the Earth. Light, as we have every reason to believe, possesses both these properties. It has a definite velocity—about 186,000 miles a second—and there are very strong grounds for believing that its movement, even when it is propagated from a point on the Earth, is independent of any movement which the Earth might have. By virtue of these properties, light is a legitimate substitute for the elastic balls of the traveller. No particular theory of light is necessary to justify the substitution. So long as light has a finite and constant velocity—which has been proved—and moves through space at a speed independent of the speed of the material body from which it is emitted—which no one, in the face of known facts, seems able to doubt—light may consist of corpuscles or etherial waves or anything else ; it is, in any event, a perfectly fair thing to use in the experiment we are proposing.

No one, we say, had any serious doubts, when Michelson and Morley performed this experiment in 1887, that the two beams would complete their respective journeys in different times, and so demonstrate once more the movement of the Earth. To place the result beyond all possibility of doubt, Michelson and Morley decided to perform the experiment twice, at times separated by a six months' interval. According to the astronomer, the Earth in this interval would have reversed the direction of its motion, and whatever its velocities might come out to be in the individual experiments, they should differ by $2 \times 18\frac{1}{2} = 37$ miles a second—the change undergone by the velocity of the Earth in the six months' interval. Judge, then, of the consternation which was aroused in the mind of everyone concerned when the two beams, in each experiment, arrived back at precisely the same time ! The experiment was repeated, but, no matter when it was performed, the result was always the same. This meant, of course, that by a universally accepted test the Earth was shown not to be moving. But, by equally powerful arguments, the astronomer maintained that it *was* moving. The passenger had demonstrated that he was at rest ; the geographer and signalman had demonstrated that he was moving. The world, which was the world of all of us, had lost its unity : it was one thing to the astronomer and another thing to Messrs. Michelson and Morley. The foundations of Science received the greatest shock that they had ever experienced, and the whole edifice of physical conceptions seemed about to fall.



[E.N.A.

HENRI BERGSON.

M. Bergson has considered the relations between time and space from the philosophical standpoint. He has emphasised the distinction between space and time which, from the purely scientific standpoint, tends to be obliterated. No necessary antagonism, however, is involved.

What was to be done about it ? It was impossible to suppose that Messrs. Michelson and Morley were mad, and consequently to ignore their observations. Neither could such a supposition be entertained with regard to the astronomers

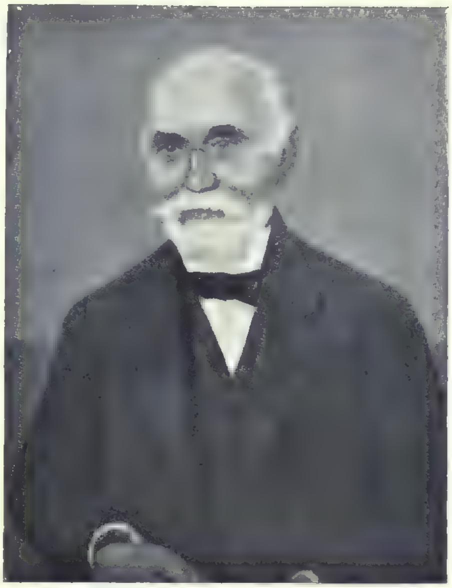
who declared that the Earth moved. Here were two sets of unquestionable observations of the same Earth, that were directly at variance with one another. We have seen that the method adopted by Science in such cases is the adjustment of its ideas of the external world in such a way as to harmonise the opposing views. But this course is legitimate only when such an adjustment can be made. In the example of the mirage which we have used previously, the observations of those who saw and of those who did not see the mirage were harmonised by attributing the phenomenon to a departure of light from its customary rectilinear path. For this explanation to be justified, it had to be shown that light could so behave in certain circumstances, and also that those circumstances were present when the mirage was seen. It so happened that these things could be shown, and consequently the external world was preserved. But in the new *impasse*, what satisfactory adjustment of our ideas is possible ? A body is moving and it is not moving ; the same body is one thing to one observer and another thing to another observer. How can the conception of an external material world be maintained in the face of these facts ?

After many years of reflection on the problem, the majority of scientists have come to the conclusion that it cannot be maintained ; the world of matter, which Science has always thought so safe a field for investigation, is found to be a chimera. There seems to be no satisfactory escape from this conclusion. Our immemorial assumptions must go. The solid objects which have always appeared to be independent of us who perceive them can no longer be regarded as independent ; they are subjective, taking a form and content determined by their relation to the observer. This is the principle of relativity. The external world of matter situated in space and time is not a unique thing ; it is all things to all men. What was thought to be absolute is relative, and there is nothing either large or small, quick or slow, heavy or light, but thinking makes it so.

This is all very well, but what becomes of Science now ? We have seen that if the external world is not absolute, Science is at once dethroned and Metaphysics becomes the only possible medium, in the purely intellectual sphere, for the approach to ultimate truth. Have we, then, reached this melancholy state, and have the devotions and martyrdoms of centuries been paid to a false goddess ? It would seem so, but there is just one avenue which may, if we are bold enough to take it, lead us out of this dungeon of despair. We have been forced to acknowledge that the world of matter and of motion is not absolute, but might it not be that there is an external world, not consisting of matter and motion but represented in some way by them, that *is* absolute ? It is not easily conceivable, because we have become so accustomed to looking upon the world as a collection of material things moving in space and time that we have almost lost the power to imagine any alternative. But we are in a desperate plight. The world of matter, space and time must be acknowledged to be relative, whether we like it or not, and we must either give up the notion of an external world and the sovereignty of Science, or else find an

A JOURNEY IN FOUR DIMENSIONS.
Just as the appearance of a penny varies with the point of view, so the length and time of a journey vary according as they are measured by the traveller or a stationary observer. And just as a three-dimensional definition of a penny reconciles the various observations, so does a four-dimensional definition of the journey.

external world that is different from that which we have always believed in. We may not, of course, be able to find such a world—that remains to be seen—but we can try, and if we succeed we must be prepared either to accept it, and abandon our old idea of a material universe, or else cling to our old idea and admit that Science is subject to the vagaries of our own minds and bodies.



PROFESSOR H. A. LORENTZ.
Professor Lorentz is one of the greatest of mathematical physicists. His researches in electromagnetism and the theory of optics made it possible for Einstein to propound his first statement of the principle of relativity in 1905.

The way in which we must set to work is this. We have found that to one observer the Earth is moving, while to another it is not. What do we mean by motion ? We mean simply a continuous change of position in space as time goes on, and we measure the rate of motion by the distance covered in a stated time. But now we are forced to admit that the measure obtained by one observer may differ from that obtained by another, and the only way in which we can explain this is by supposing that different observers measure space and time differently—or, in other words, since our world of matter and motion is crumbling away, that they have different spaces and different times. But in what way do their spaces and times differ ? Evidently in such a way as to give the differences that we find in their measurements of the motion of bodies ; we must find out, for example, why Michelson and Morley always found the Earth to be at rest, at whatever time of the year they made their experiment, and deduce from that remarkable observation how their measures of time and space may be assumed to have varied. In this way we may be able to find some relation between the spaces and times of different observers—a relation which will depend on some peculiarity of their physical condition—which will enable us to determine the spaces and times of all when those of one are known. The possibility of re-establishing the independence of the external world will then depend on whether or not we can find some combination of the space and time measurements that will be the same for everybody. If so, then that combination must be the mathematical indication of the existence of something external that is the same for everybody, and we shall have re-established the sovereignty of Science. If not, then Science is lost, and there is no external world.

The investigation is obviously a mathematical one, and it turns out that the variations of time and space are associated, in a most remarkable way, with the velocity of light. If Michelson and Morley had been able to use guns and elastic balls, fixed on the Earth's orbit, instead of beams of light, they would have found a movement of the Earth identical with that predicted by the astronomer—at least, so they would have thought. But actually it appears that the result would have depended on the speed with which the balls were discharged : the greater the speed of the balls the slower would have been the movement indicated for the Earth. For all ordinary speeds, and even for speeds very much greater than those which we can produce in modern projectiles, the variation would have been so small that Michelson and Morley would not have detected its existence ; but at speeds approaching that of light it would have become obvious, and if the balls could have been projected actually with the speed of light, then no matter how quickly the Earth might have been moving, the experiment would always have shown that it was not moving at all. These phenomena are all embodied in the statement that if two observers are moving uniformly with respect to one another, their measures of lengths and time intervals (in other words, the spaces and times which they use) will differ in a manner depending on the ratio of their relative velocity to the velocity of light. This is a perfectly general principle of which the Michelson-Morley experiment affords only one particular example. The reason why it has only just come to light is that the ratio between

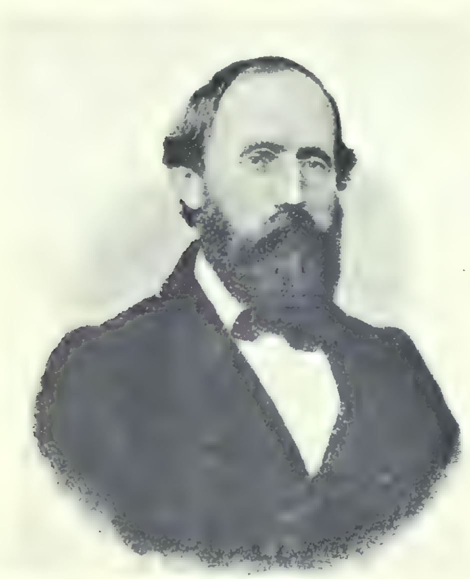
any velocity to which we are accustomed—even the velocities of the planets and the stars—and the velocity of light is so very small as to make no perceptible difference between our spaces and our times. We thought we were living in the same world of matter, space and time because the differences between our worlds were too small for us to detect.

ORBIT OF MERCURY

The orbit of Mercury round the Sun is an ellipse (here exaggerated) which slowly rotates in its own plane. The theory of relativity supplies the only tenable explanation of the rate of the rotation.

Can we, now, find a combination of our measurements of space and time that will be the same for everybody ? That is the crucial question for Science. It so happens that we can. Suppose a man travels with uniform speed in an aeroplane from London to Paris, and, while travelling, measures the distance between the two places and times the journey by his watch. Suppose also that an observer, situated in a very high tower from which he can see both London and Paris, also measures the distance between the two places and the time occupied by the journey. Their measures, both of time and of space, will differ —imperceptibly it is true, but we will suppose that their instruments are so exceedingly delicate that they can observe the differences. They will find that, if each of them subtracts the square of his time measurement from the square of his space measurement (both expressed in certain defined units), he will obtain a result identical with that of the other. The individual measurements of space and time are at variance, but this simple combination of them is the same for all observers, no matter how they are moving, so long as their relative velocity remains constant.

Here, then, is the clue to the external world : it must be something whose properties are measured by a combination of space and time measurements, and not by space measurements and time measurements independently. Matter has failed us because it is characterised by independent measurements in space and time. If a piece of wood is three feet long to-day it may or may not be three feet long to-morrow ; there is no necessary association between its size and the date. But in order to describe the external world in a manner acceptable to all, we must describe it in terms of something which necessarily involves both time and space, so that we cannot measure it without making measurements of both time and space. All our measurements will then be capable of expression in the form (space measurement)^2 minus (time measurement)^2, and the world measured in this way will be a world common to all. Such a world is the world of *events*. An event—something which happens—has both a place and a time, and is not completely specified unless both its place and its time are stated. When the schoolboy says, " Battle of Hastings, 1066," he specifies an event completely, for he indicates the place (Hastings) and the time (1066). Similarly, when he says, " Battle of Waterloo, 1815," he specifies another event completely. It is possible to look upon the whole of Nature as an aggregation of events. Instead of speaking of the object of our perceptions as a piece of matter—a block of wood, for example—we can speak of it as an event—the existence of the block of wood at a certain place during the time it takes us to perceive

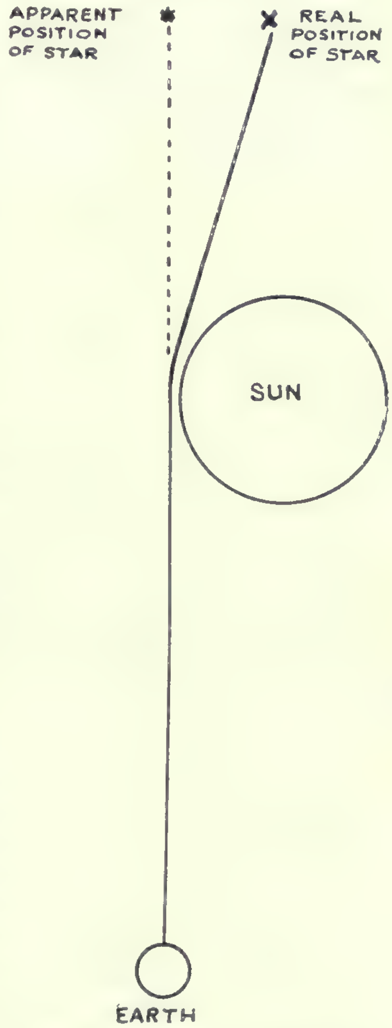


From " The Story of Euclid."
By permission of Messrs. George Newnes, Ltd.

BERNHARD RIEMANN.

Riemann, in a famous paper entitled " On the hypotheses which lie at the basis of geometry " (1854), showed the character of the relation between geometrical systems and physical experience. Einstein adopted Riemann's form of reasoning in presenting his theory of relativity.

it. If we perceive it again five minutes later, we may be perceiving the same piece of matter, but our new perception of it is another event because it is characterised by a different measurement, in time at least, from the first. Nature, according to this view, is the sum-total of events, and the only measurements we can make that will be corroborated by others moving with respect to us are measurements of the interval between events. The interval between two events is defined as (space interval)^2 minus (time interval)^2. Thus, to find the interval between the Battle of Hastings and the Battle of Waterloo, we must square the distance from Hastings to Waterloo and subtract from the result the square of the time interval between the years 1066 and 1815. An observer on a possible planet of Arcturus, if he perceived the two events, might measure the space interval and the time interval differently, but he would find the same difference between their squares. If we are to vindicate the godhead of Science we must learn to look on Nature, not as a collection of inert objects moving in a stationary space and an independent, uniformly flowing stream of time, but as a self consistent, continually renewed body of events, having neither beginning nor end in space or time, but related to one another by their situation in a four-dimensional continuum formed of both space and time. All our measurements must be measurements of intervals in this continuum, and Science must express its laws in terms of these measurements or not at all.



DEFLECTION OF LIGHT BY MATTER.

According to the theory of relativity, a beam of light passing near the Sun is bent inwards, so that stars apparently near the eclipsed Sun seem slightly displaced outwards. The effect, which has been observed, is much exaggerated in the figure.

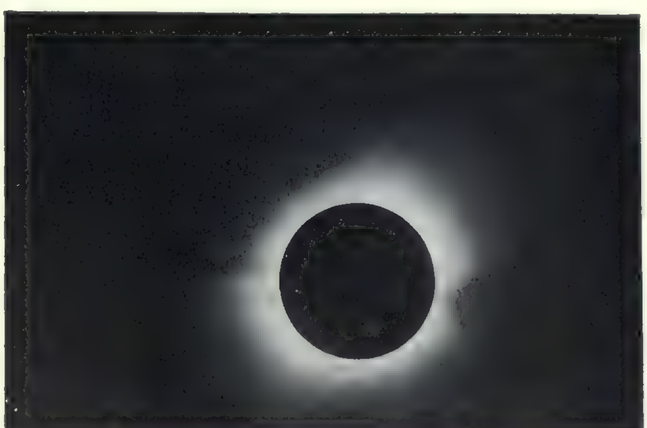
Such a view may seem very artificial, but we cannot avoid it without losing the external world altogether. It is not a case of choosing between it and our familiar world of matter ; it is a case of accepting it or denying the foundations of Science. The Michelson-Morley experiment makes it for ever impossible to establish Science on a foundation of matter. If matter is a fundamental unit, space and time are fundamental and independent entities, and then it inevitably follows that there are as many actual external worlds as there are people in relative motion, and an infinite number of possible ones—which is as good as saying that there is no external world at all. And, if we consider the question carefully, we shall find that the view of Nature as an aggregate of events is not so artificial after all. We must allow for the accumulated prejudices of untold generations which have been able to think of the world as material because they have never had practical experience of velocities approaching the velocity of light. So far as our ordinary everyday experience goes, we can, with quite sufficient accuracy, think of an external material world, and we must not allow this fact—this privilege, shall we say ?—to influence us in our search for ultimate truth. Despite the apparent impossibility of denying the objectivity of matter, philosophers have done so on quite other grounds than those of physical experiments, and we may well believe that, if we had been living in a world where velocities of the order of the velocity of light were common, we should never have been subject to the illusion that has beset us until now.

Perhaps in this new view of Nature we may catch a glimpse of the possible influence of relativity in the field of ethics. We have thought of ourselves as existing in a world of matter ready-made,

which we have a limited power of arranging in time and space. But if the world consists of events, and not matter, then, so far as we can control events, we are the creators of the world: we do not find it ready-made—we help to make it. We cannot here follow up the implications of this idea; we are concerned with astronomy, and the events of astronomy are quite beyond our control. But we may regard it as a sign that relativity is not altogether the abstract, detached conception that it is often assumed to be.

When we come to apply relativity to the phenomena of astronomy, we meet at once with a serious difficulty. So far, we have only faced the problem of discovering an external world that is the same for all who are moving with respect to one another with *uniform velocity*. We have found that, for all such people, there is a common external world of events separated by intervals measured by expressions of the form (space interval)^2 minus (time interval)^2. But in astronomy, one of the outstanding facts is that bodies never move with uniform velocity: their velocities are always changing—in magnitude, or in direction, or in both. The planets travel round the Sun in ellipses, and their speeds vary somewhat during the journeys. The components of double stars are continually changing the directions of their movements. The single stars appear to move uniformly, but it is believed that that is only because their changes of speed and direction of movement are so slow that we have not yet observed them. Wherever we look there is change of direction or speed of movement, and we have not shown that, when this occurs, it is possible to postulate a common external world for all the parties concerned. It follows, then, that we have our work to do all over again. Of course, if we had been thorough-going in our calculations and absolutely accurate in our measurements, we should have taken account of variable motion in the mathematical consideration of the Michelson-Morley experiment. The Earth is moving non-uniformly, and it was the movement of the Earth with which we were then dealing. But during the time occupied by the Michelson-Morley experiment, the change of motion of the Earth, both in speed and direction, was so small that it had to be ignored in view of the unavoidable errors inherent in our observations. It was far too small to serve as a basis for generalising with regard to variable motion. There was no alternative but to deduce from it the effect of *uniform* motion on our space and time measurements, and leave the larger problem to be dealt with in some other way.

It might seem that our discussion of the Michelson-Morley experiment was therefore a waste of time. We have established an external world for people in uniform relative motion, and people—or, at least, bodies on which there might be people—are *not* in uniform relative motion. We have apparently only shown that it would be legitimate to speak of an external world if Nature would kindly limit herself in a way which she is not prepared to do. But, as a matter of fact, we have done much more than that. We have found an alternative to the world of matter in space and time, namely, the world of events. Although the particular unit of measurement—the quantity (space interval)^2 minus (time interval)^2—might no longer be unique when the relative velocities of observers vary, there may still be some other unit of measurement, quite consistent with the conception of events as the brickwork of Nature, that will make the world consistent for all kinds of movement. If we can find such a unit we shall save the external world, so far as we can see, completely; if not, then the world of events must follow the world



By permission of [*The Astronomer Royal.*

THE SOBRAL ECLIPSE, 1919.

The above photograph of the eclipsed Sun was taken at Sobral on the 29th May, 1919. The points, indicated by short lines on either side, represent stars whose positions on the photograph reveal the displacement of their light by the Sun.

of matter into the limbo of illusions. It is not only recently that variable motion has given rise to difficulties in Science, but the previous difficulties have been of a different character from the present one.

From "The Story of Euclid." By permission of Messrs. George Newnes, Ltd.

NICHOLAS IVANOVITCH LOBACHEVSKY (1793–1856).

Lobachevsky was one of the originators of "non-Euclidean geometry," which depends on the realisation that a property of space which Euclid regarded as axiomatic is not necessarily true of the actual space of experience. He constructed a self-consistent system of geometry different from Euclid's.

Newton proposed to himself the task of discovering why the velocities of bodies varied. He believed, of course, in an external world of matter, space and time, and he assumed, quite gratuitously, that the natural thing for a body to do was to move always with uniform velocity. Since bodies did not move with uniform velocity he invented *gravitation*—an agency which interfered with the course of Nature in such a way as to produce the variations of velocity which he found in the Moon and the planets. Our point of view now is different. We do not believe in an external world of matter, space and time; we do not, in fact, believe in *any* external world—we are trying to find one. And we do not assume anything at all about the natural movements of bodies; we take the movements as we find them, and look for a world that is independent of them. Newton assumed that he knew what Nature was, and tried to show how she executed her movements; we accept the movements as ultimate phenomena, and try to find out what Nature is. Our attitude is therefore just the reverse of Newton's. Whereas he arrived at gravitation from his starting-point of matter, space and time, we begin with the phenomenon which appeared to necessitate gravitation —variable motion—and try to arrive at a world that can replace the world of matter, space and time. And if we can do it we shall have no need to retain gravitation as a force interfering with natural tendencies. We shall have our world which is complete in itself, inasmuch as it is the same for everybody, no matter how he or she is moving. Newton's problem will not exist for us, because there will be no interference with the new world which we shall derive.

We are seeking, therefore, almost to repeat Newton's work backwards. Almost, but not quite, for we must not arrive at his starting-point—a world of matter, space and time. But it is evident that, since his conception of gravitation explains the movements of bodies with almost complete accuracy, the course which we must take must not depart very much from the track which he has left. We might say of Newton's work, just as we said of the first discussion of the Michelson-Morley experiment, that, though it is not final, we may profit by the suggestions it offers us in coming to a conclusion which shall be final. And if we look at it with that object in view, we cannot help noticing that the central point of Newton's conception was the importance of *mass*—the quantity of matter in a body. The whole cause of variable motion, according to Newton, lay in the fact that matter had mass. If the Sun had no mass, the planets would not move in ellipses, and if it had a mass different from that which it has, they would not move in the same ellipses as they do. The mass of matter is in some way associated with the phenomenon of variable motion, and we shall do well to see if we can introduce it into our measurements in the world of events in order to secure for that world the complete independence of the state of motion of the percipient at which we are aiming.

Now that we have arrived at this point, we notice at once that there was a strange omission from our previous method of measuring the new world. We had absorbed matter, space and time into a single world of events, and we were proposing to measure that world by combining space and time measurements alone, ignoring completely the amount of matter concerned in the phenomena. Apart altogether from outside considerations, it is evident that such a proposal could not possibly suffice

to measure a world of events. We have no need—as yet, at any rate—to conclude that the world of events has failed us ; we must learn to measure that world adequately before we can draw any conclusion at all on that point. And now, to emphasise the truth of this statement, comes the example of Newton, who solved a similar problem, regarded from a different point of view, by a judicious use of mass, the neglect of which is so conspicuous in our earlier suggestion. It is clear that the first thing that we must try to do is to find some combination of space, time and mass measurements that will be the same for everybody, in any state of motion at all.

At this point, of course, the investigation again becomes mathematical, and its details must be passed over. The result, however, is that, not only can we find such a combination, but we can find several of them, and there may be others that we have not yet thought of. The first solution of the problem, as everyone knows, came from Einstein, and Whitehead has since shown that there are at least three other possible combinations that will reconcile all the observations that have been made up to the present. There are consequently four possible external worlds of events, and instead of having to dethrone Science, as it seemed we might have to do, we are, in the end, left wondering on which pedestal to place her. We do not believe that the world actually is a manifold : the choice at our disposal simply means that our present imperfect knowledge is consistent with more than one explanation. All of the possible ways of combining our measurements have their own implications which, though they are identical so far as recorded observations go, differ in details not yet investigated. The difficulty about the differences is that they are exceedingly small—too small to be detected with

THE IRON SPECTRUM.

The illustration shows two photographs of a short length of the iron spectrum, of which the upper is slightly displaced to the right (the red side) of the other. The displacement here was produced mechanically, by moving the photographic plate. The displacement of the solar lines required by the theory of relativity is only about one-eighth of that shown here.

our present experimental resources. Until our measurements can be extended to much smaller quantities than we can deal with now, or, by the passage of time, the quantities to be measured grow large enough to come within our means, the decision must remain in abeyance. But, whatever it may be, the principal object of our discussion has been achieved, and the existence of a world consistent with everyone's perception of it has been established.

Although we cannot yet distinguish between the possible units of measurement in the world of events, we can see that they all agree in requiring certain phenomena inconsistent with the old units of measurement in the world of matter, space and time, even when the latter world is amplified by the introduction of Newton's conception of gravitational force. There are three outstanding phenomena of this kind, which must be mentioned. First of all, in a world of events the paths of the planets must be slightly different from the paths which Newton's conception prescribes. The differences are exceedingly small, and for most of the planets are beyond the range of detection ; but for Mercury, the planet nearest to the Sun, a departure from the Newtonian path is quite observable, and has, in fact, been known for a long time, though no satisfactory cause has previously been suggested. The substitution of a world of events for a world of matter, space and time automatically removes one of the great unsolved problems of astronomy. The path of Mercury can be regarded as an ellipse which rotates slowly in its own plane : the problem relates solely to the rate of rotation. The orbit has revolved too quickly for the old view of Nature ; its rate is quite consistent with the new view.

The second of the phenomena is that, in a world of events, the path of a ray of light must depend on the masses of the material bodies in the universe. It has been known for a long time that matter

affects the paths of light-rays (there are the phenomena of reflection, refraction and absorption of light, for instance), but only when the light actually encounters the matter, and even then the effect has no obvious connection with the *mass* of the matter. It has, furthermore, been suggested that light may be subject to gravitation just as matter is, but there has been no evidence of such a thing. But in a world of events, however it is measured, light *must* take a course depending on the distribution of mass in the Universe—or, speaking more strictly, depending on the other events of Nature—and that course, no matter who observes it, must be different from the course which the light, even if it were subject to gravitation, would take in the old world. The effect required by the world of events has been observed by photographing the stars apparently near the Sun during a total solar eclipse. The starlight which passes near the Sun suffers a deflection which makes the stars appear to be displaced from their normal positions on the celestial sphere. This displacement has been measured by various astronomers at two eclipses—in 1919 and 1922—and there is a general agreement that the world of events is justified by the results.

Lastly, in a world of events, not only the path, but also the wave-length, or frequency, of light must be affected by mass. This should be observable by comparing the wave-length of light emitted by atoms in the neighbourhood of a very heavy body with the wave-length of light emitted by similar atoms in identical circumstances except that the heavy body is not near at hand. For example, if we compare the positions of the iron lines in the spectrum of the Sun with the positions of iron lines produced under the same conditions of temperature, pressure, etc., on the very much less massive Earth, we ought to find that the solar lines are displaced slightly towards the red end of the spectrum as compared with the terrestrial lines, and the displacement should be quite large enough to be measured. Some observers claim that they have verified the existence of this displacement, while others find no evidence of it. The truth of the matter is probably that we do not know the physical conditions in the Sun sufficiently well to be sure that we have imitated or allowed for them on the Earth. Spectrum lines may be displaced by many agencies, and the time has not yet arrived when we can say with certainty how many of them influence the solar light, and to what extent they do so.

STATUE OF SIR ISAAC NEWTON, TRINITY COLLEGE, CAMBRIDGE.

Sir Isaac Newton, whose law of gravitation has guided astronomy for more than 200 years, was an undergraduate of Trinity College, Cambridge. His law was based on the assumption that matter, space and time are absolute.

The whole body of reliably observed phenomena, as seen from every point of view, is therefore consistent with the existence of an external world—only it must not be a world of matter in space and time. If we ask ourselves, after all this discussion, what are the ultimate units of the world which

Science can safely take as the object of her studies, we must answer that they are events. Matter, space and time are abstractions—the results of our individual analyses of the fundamental events, and they partake of the state of the analyser as well as that of the events. This is the general, the catholic meaning of the principle of relativity. And it is not difficult to understand; it is not complex —it is simple. It is reached along a rugged mathematical road, and its laws are strange, but they are wonderfully consistent. The word "relativity" is perhaps an unfortunate one; it emphasises the negative aspect of the new position. Matter, space and time are relative, it is true, but there is also an absolute—the event. "The principle of absolutism" we might say, for the principle dethrones the relative and exalts the absolute. To the ordinary intelligent thinker, who looks for the heart and not the members of scientific ideas, the principle should present little difficulty. It is the man of Science who has to bear the brunt of the battle. He has to investigate a new world and adopt a new mathematics, and no one in this generation can destroy at a stroke the old methods and terms of thought and adopt the new ones. The physicist and the astronomer must still, for mathematical purposes, use the old conceptions of mass, space and time, and modify their measurements to allow for the imperfection of their conceptions. They have to talk of a "warp in space," and use other apparently unintelligible notions, because their minds are human. By assuming such enormities they can make the world amenable to their irrepressible mental habits and tendencies, and avoid the necessity of destroying the past achievements of Science before aiming at new ones. But there is no need for the non-specialist to concern himself with the technical devices of the scientist. It is not only unnecessary—it is actually harmful for him to try to imagine what is meant by the warping of space. That is not the principle of relativity; it is an artificial mode of thought

R.A.S.

LOG OF NEWTON'S APPLE TREE.

Newton is generally supposed to have developed his idea of universal gravitation from the observation that an apple falling from a tree moved towards the centre of the Earth. This picture shows a portion of the tree in question.

which Einstein has had the genius to devise for the use of the scientist faced by the new situation which the principle of relativity creates. The central idea of relativity is that the world outside us is an aggregation of events, of units in which space, time and matter alike have their source. If that is simple, then the principle of relativity is simple.

And we need not greatly concern ourselves with the uncertainty that still remains as to the way to measure the new world. It is true that there are four possible ways, and there may be more. Doubtless, in time we shall gradually eliminate the false and detect the true. But, in the meantime, the world is no less definite for us because we are not sure how to measure it. On the contrary, our uncertainty arises from the fact that we see the new world more clearly than, until recently, we saw the old, and can recognise finer shades of distinction and a greater wealth of possibilities than we could do, say, 100 years ago. But even in the old world, some time before its validity as a unique objective existence was doubted, uncertainties arose as to its measurement, which could only be settled by experiments too delicate to be performed. Before the principle of relativity was dreamed of, the character of the supposed absolute space was called in question. It was recognised that there were at least three radically distinct possible spaces, one of which was the space of Euclid, and that only experiment could decide which was the actual space of Nature. Furthermore, it was known that in certain circumstances the mass of a body could change ; and as for time, no one was ever able to state what time was—we only knew how to measure it and could never be sure that our measures represented equal units of the mysterious thing we were measuring. The world of events is not less, but more definite than the world of matter, space and time which it replaces. We have not defined it quantitatively, but we have a clear idea of what it is.

[E.N.A.

DEFLECTION OF STARLIGHT BY THE SUN.
It is only during a total solar eclipse that the deflection of starlight by the Sun can be observed. At other times during the day the stars are put out by diffused sunlight in the Earth's atmosphere. This picture shows how the sky would appear in the daytime if the Earth had no atmosphere.

If we try to look forward into the future of Science we see an endless vista of reformations of the external world. It has been so in the past, and there is no sign of an impending change. Only once in an epoch does a reformation so radical as the principle of relativity arise. The world was based on matter, space and time by the Greeks more than 2,000 years ago. The world thus established was modified, slowly and hesitatingly, through centuries, till Newton made the greatest change in its history by adding universal gravitation to it. Gradually the process went on ; light, magnetism, electricity demanded acknowledgment ; atoms and molecules were introduced ; space became associated with matter and the æther was postulated ; non-Euclidean geometries arose ; electrons were isolated. Step by step the world founded on matter, space and time was built up and modified, until at last the foundations could sustain it no longer and it fell. The world of events satisfies us now ; will it always do so ? We cannot tell. It will be modified ; false methods of measurement will be eliminated, and so long as human minds can find a way to retain it as a legitimate external world they will not hesitate to modify it for that end. But a time may come when even events will

not compose a world consistent with all the observations that will then be possible. If that should happen, we cannot see what the consequences will be. Perhaps a new world will be established on a basis beyond our conception ; if so, yet another indefinite future will stretch out for Science. But it may be that no such world will be possible ; it may be that the postulate of an external world will have had its day, and that its children will have risen up to destroy it. Should such a time arrive, the goddess of Science will lay down her crown at the feet of Philosophy. Nature will be transformed, and we shall be transformed too, for we shall comprehend Nature. But for the present that is a possibility that we have no need to contemplate. We are at the beginning now of a new era, and the way is clear for incalculable advances before the next check to the progress of Science might be expected. We are entering a world of new possibilities, and we can already see that problems which we have thought insoluble may take on a new meaning and yield to our inquiries.

CHAPTER XIX.

TIME : ITS DETERMINATION, MEASUREMENT, AND DISTRIBUTION.

By C. O. Bartrum, B.Sc., F.R.A.S.

P. Collins, Reading.

VERTICAL GNOMON.

A primitive means of knowing the time of day and the seasons of the year. The midday shadow is shortest at the summer solstice, longest at the winter solstice, and of intermediate length at the equinoxes. At these last epochs the ratio of the length of the shadow to the length of the gnomon is the tangent of the latitude of the plane.

FROM the earliest ages the alternation of light and darkness has provided man with a natural unit of time, the solar day, the period between successive returns of the Sun to the same place in the sky. Modern dwellers in towns, accustomed from childhood to live surrounded by public clocks, maintained at sufficiently correct time in some mysterious way of which generally they have no knowledge, can realise the conditions of life among primitive folk only with an effort of imagination. In the remote times, when all human life was simple, before the days of artificial light, when one worked while it was day and work was impossible at night, the position of the Sun in the sky was the only and sufficient indication of the passing of the time of day. Those whose duties kept them awake at night would with a little experience know by the fading twilight, the position of the stars and the approaching dawn how the night was passing. A glance at his shadow on the ground conveys to-day to the simple native of India and of other countries knowledge of the time sufficient for his needs.

AN AURORA

Aurorae have been observed in all parts of the world, but they are most frequently seen in the Arctic and Antarctic regions. Their appearance is known to have a definite relation to the occurrence of magnetic storms on the Sun and Earth. Aurorae occur at great heights in our atmosphere and take various forms, the commonest being described as "arches," "curtains" and "streamers." The last-named resemble the beams of searchlights, and exhibit various colours. Pale yellows and greens are commonly seen, other "streamers" appearing pure white or rose-pink. The constant change of position and relative brightness of the different portions of an Aurora adds to the beauty of the spectacle.

The simple expedient of driving a stake vertically in the ground and watching the changing direction of its shadow cast by the Sun served for ages, when greater accuracy of knowledge of the march of time was needed (*see* figures on pages 688 and 689). When the shadow of such a gnomon (Greek *gi-gnosko*, I know) was reduced to its shortest length midday was indicated at all times of the year. The shadow of a vertical stake does not, however, move uniformly with time except at the Earth's poles, and, what is more serious, its position at any time of day except noon differs at different seasons of the year. A great step in advance was made when the gnomon was set up parallel with the Earth's axis of rotation, pointing to the pole of the heavens. Under these conditions the Sun will always appear to move uniformly round the gnomon and the shadow will be in the same direction along the ground or dial (Latin *dies*, a day) at the same apparent time of day all the year round (*see* figure on page 691). We then have the true sun-dial.

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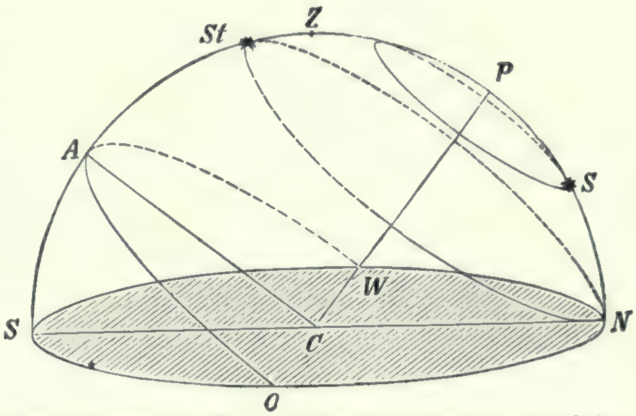
ANCIENT STELE USED AS A GNOMON.
Such a monument was probably used for the purpose of following the course of the seasons by noting the length of the shadow cast by the Sun at midday.

We read in the Book of Isaiah, Chapter xxxviii., that the Lord commanded Isaiah to say to King Hezekiah that He would deliver him from the King of Assyria and that as a sign "I will cause the shadow on the steps [or degrees], which is gone down on the dial of Ahaz with the Sun, to return backward ten steps. So the Sun returned ten steps on the dial whereon it was gone down." Ahaz, the father of Hezekiah, lived in the Eighth Century B.C. and we have here what appears to be the earliest reference to a solar time indicator. Various forms of gnomon were known to the Chaldeans, and were said to have been introduced into Greece by Anaximander (611–545 B.C.) and, according to Josephus, to have been used in Egypt from very early times. To Berosus, the Chaldean philosopher, is attributed the invention of the hollow dial cut in a block of stone. A fixed bar cast a shadow on its concave surface which was divided by lines to mark the twelve hours of the day. Such an instrument is referred to by Herodotus as having been derived from Chaldea, and it was known in Greece and Rome. The octagonal Tower of the Winds at Athens, attributed to the Fourth Century B.C., bears dials on all its eight sides, each of which carried a gnomon, as shown from the holes still to be seen. These dials, however, are believed to have been added centuries after the erection of the Tower. The sun-dial has been used up to the present day. When accurately adjusted to the latitude of the place, correctly oriented to the meridian, and the dial properly calculated, it will give the apparent time accurately to two or three minutes (*see* figures on pages 690, 691).

As civilisation became more complex and men congregated in large communities and came to co-ordinate their movements in common pursuits, some means were required of measuring time that were not continually dependent on the Sun. The water-clock, or clepsydra, appears to have been the earliest of such means. Such instruments are said by Sextus Empiricus to have been used by the Chaldeans, and by Vitruvius to have been invented by Ctesibius of Alexandria about 120 B.C.; a water-clock was used in the Athenian Courts of Justice to limit the length of speeches, and by Ptolemy the astronomer (Second Century A.D.) for time observations. Tycho Brahé (1546–1601) is said to have measured intervals by a clepsydra. This method of measuring time was to allow water to flow from a small hole into a vessel and to provide means by which the height to which it had risen in this vessel could be read off. The flow was supplied from a small vessel maintained constantly full, the overflow passing away by a waste. The small vessel was in turn supplied from a larger vessel. In this way the head of water was kept at a constant height and the flow approximately regular. In those days, and until the Fourteenth Century in Europe, the hour was a twelfth part of the interval

between sunrise and sunset, and consequently its value was less in winter than in summer. To allow for this inequality ingenious contrivances were made to adjust the divisions on the indicator of the clepsydra to the varying length of the day (*see* figure on page 693).

A means for measuring time used from early days in India, and still in use among the natives, is the *pāni ki ghurry* (water-clock), consisting of a thin metal basin with a hole in the bottom. This is set afloat in a larger vessel of water; the water enters by



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THE PATH OF THE SUN IN THE SKY.

C is the position of the observer, N O S W the plane of the horizon, P the pole of the heavens, O A W the equator of the heavens, N P A S the meridian, P C N the latitude of the place. The Sun appears to move uniformly, parallel to the circle W A O, each day, crossing the meridian at apparent noon. In summer the circle is higher; at the equinoxes the Sun is on the equator; and in winter the circle is lower.

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VERTICAL SUN-DIAL.

Sun-dials are commonly found on mediaeval churches. As with the horizontal dial, the gnomon is fixed parallel to the Earth's axis and points therefore to the pole of the heavens.

the hole, and after a certain interval sinks the basin. It is then raised, emptied, and the process repeated, the number of repetitions being counted. Modern archæologists have found very thin bronze basins similarly provided with a hole among British remains of the time of Cæsar's invasions, which can only be explained on the supposition that they were used by the Britons as time measures in a similar way to the ghurry referred to above. Examples of these British basins are now in the British Museum. In Cæsar's "Gallic War" he speaks of measuring time in Britain "by accurate water measures," and this sentence has been taken to refer to the use of the clepsydra brought over by the Roman armies. It now seems possible that Cæsar was speaking of the use by the Britons of these bronze basins.

The sand- or hour-glass was in use as a rough time measurer many years before the beginning of the present era, but its important function has been its use by seamen in combination with the log for determining the speed of the ship through the water. The log, or log-ship, was a flat piece of wood, which was weighted along one edge so that it floated upright, and to which was attached the log-line. This line was knotted at calculated intervals. When an observation was taken the log was thrown over the side into the water and the line allowed to run out freely through the hand. The number of knots that passed the hand while the sand was running out of the glass indicated the "knots," or the speed of the ship in nautical miles per hour. Until quite lately the use of the sand-glass for this purpose was taught to naval seamen. Various patent logs are now used in place of the old log and sand-glass. These depend for their action upon the rotation of a screw as it is dragged by a

rope in the wake of the ship, and the rotations are registered on a dial. Mention may also be made of the use sometimes made of a sand-glass in churches till the last half-century to limit the length of sermons, and in kitchens for timing the boiling of eggs. King Alfred is said to have measured time by the burning of candles. An ancient custom has been retained in the old Hanse city of Bremen whereby the time allowed for the auction of property is limited by the burning of a small candle.

The accurate measurement of time became possible only with the development of the mechanical clock. Before dealing with this, some attention must be given to the division of the time of day and to the different kinds of recorded time.

Sunrise and sunset are the most obvious events in the passing of the time of day. It is not surprising, then, to find that until modern times the divisions of the day were reckoned almost universally from the one or the other. With the ancient Hebrews the day began at sunset. We read in Genesis, " The evening and the morning were the first day." This custom they still observe, and it has been adopted by the Western Catholic Church, whose feasts and fasts begin at six o'clock on the eve of the appointed day. In ancient Greece reckoning was made from the evening and, according to Cæsar and Tacitus, the ancient Gauls and Germans computed their times and seasons by the night (compare our more modern se'n-night and fortnight). In Babylon the day from sunrise to sunset was divided into twelve equal parts, a division associated with the twelve divisions of the zodiac. In Palestine at the time of the Roman occupation this was the custom, for we read (Matthew xx.) that the lord of the vineyard went into the market place at the eleventh hour when it was nearly even ; Christ's death is recorded as occurring at the ninth hour, that is, at 3 p.m. of our present reckoning. We still speak of midday as noon, that is the hour for saying nones in the churches. This was the office appointed for the ninth hour, originally half-way through the afternoon, but later put forward to midday. In Chaucer's (about 1340–1400) Prologue to the " Parson's Tale," the narrator speaks of its being " ten of the clock," " by the shadow," when, as is shown by the context, he is referring to four hours after noon ; in another place he refers to the sureness of a clock, a reference that suggests that clocks were becoming known in Chaucer's time. This custom of dividing the day from sunrise to sunset irrespective of the season into twelve equal parts continued in Europe until the Fourteenth Century. The variations in length of the hour at different times of the year were inconsistent with the use of mechanical clocks, which were then coming into use, and the custom was probably discontinued on that account. In some parts of Turkey, where, with its backward state of civilisation and its ancient association with the East, we should expect to find old customs retained, the day

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HORIZONTAL SUN-DIAL.

The gnomon should make an angle with the dial equal to the latitude of the place and should lie in the meridian. It will then be parallel with the Earth's axis, and will throw a shadow in the same direction at the same apparent time at all seasons of the year.

is still divided into parts that differ in length with the season.

Such varying units of time were of no use to the ancient astronomers, Hipparchus (190–120 B.C.) and Ptolemy (Second Century A.D.). In place of these "temporary hours," as they were called, they reckoned in "equinoctial hours," that is, the twelfth part of a day at the time of equinox. Ptolemy also numbered the hours from noon through the twenty-four hours to the following noon, as has been the custom of astronomers ever since.

[P. Collins, Reading.

RING SUN-DIALS.

In general use in the Seventeenth and Eighteenth Centuries. The ring is suspended by the metal loop. A small hole in a barrel of metal, adjusted to the time of year by being moved in a groove, throws a spot of sunlight on to the inner surface, which is marked in hours. "And then he drew a dial from his poke."—*As You Like It*, Act II, Scene 7.

It seems, then, that the change that is being introduced with the Nautical Almanac of 1925, of reckoning the astronomical day from midnight, and of making its beginning agree thereby with the beginning of the civil day, involves the breaking of a very ancient custom among astronomers.

[P. Collins, Reading.

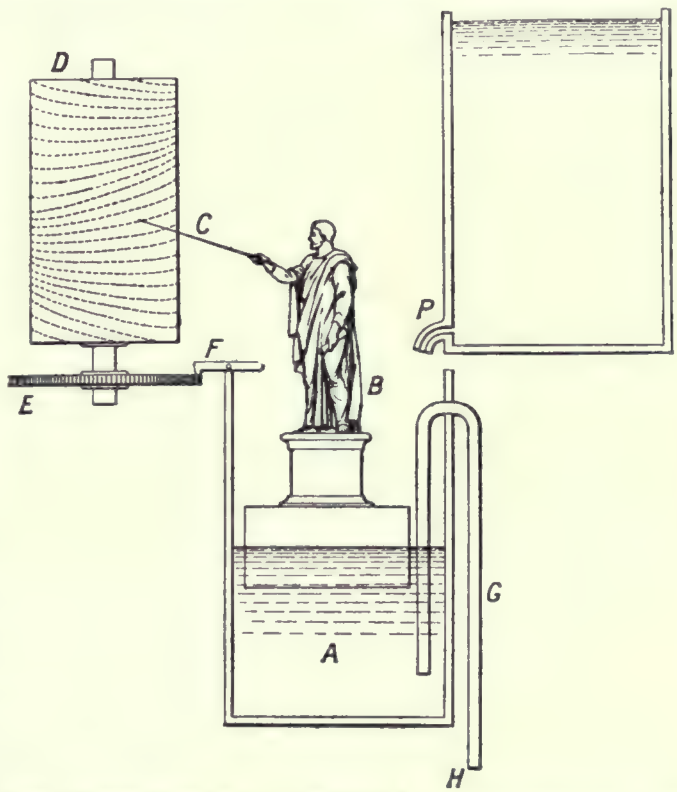
HOUR-GLASS.

Dry sand is hermetically sealed within the glass vessel. The sand flows in a fine stream through the narrow neck from the upper to the lower bulb in an approximately constant time.

The accuracy of time to which Hipparchus worked in the course of his observations involved a more subtle adjustment of the hour of day. He, and Ptolemy after him, were aware that the day from noon to noon as indicated by the Sun was of varying length. Hipparchus made a table of the "equation of time" by which to allow for this variation in length of the solar day. The following considerations will show how this variation arises. With reference to the stars, the Earth rotates with extreme regularity, undergoing only a minute secular slowing down which will be dealt with later. A sidereal day, the interval between two southings of a point in the sky, is then constant. A solar day, however, is the interval between two successive crossings of the meridian of a place by the Sun and this interval varies for two reasons. Owing to its revolution round the Sun the Earth requires to rotate rather more than 360° between two successive noons, and thus a solar day is about four minutes longer than a sidereal day. But the Earth's angular velocity in its orbit round the Sun is not uniform owing to the ellipticity of the orbit. In the winter of the northern hemisphere the Earth is nearer the Sun and its angular velocity round the Sun is consequently greater. For this reason alone the solar day would be longer at Christmas than at midsummer. Again, owing to the obliquity of the ecliptic to the equator the apparent motion of the Sun in its yearly path, even if it were uniform, would not be uniform in its relation to the equator. On this account considered alone the solar day would be shorter at the time of the spring and autumn equinoxes than at the summer

and winter solstices. The ellipticity introduces an inequality of the solar day with a yearly period and the obliquity one having a half-yearly period. In order to overcome this irregularity and to provide a uniformly flowing time for the regulation of clocks, a fictitious "mean" sun has been instituted, which travels at a uniform rate along the equator and which never departs far from the position of the real Sun. The time given by this mean sun at any place is called the mean time of the place. The amount by which the mean time is in advance of the true, solar, or apparent time is called the equation of time. This is zero on the 25 December, reaches nearly fourteen and a half minutes about the 11 February, returns to zero in the middle of April, has a negative value of nearly four minutes about the middle of May, becomes zero again in the middle of June, has a positive value of about six and a quarter minutes about the 27 July, returns to zero on the 1 September, reaches a negative value of about sixteen and a quarter minutes early in November and returns to zero again at Christmas. These changes are given graphically in the diagram, on page 694. The equation of time is calculated for noon of each day of the year and given in the Nautical Almanac. Mean time, then, is that shown by a well-regulated clock, while solar or apparent time is that given by a sun-dial or by any other means of determining the hour-angle of the Sun. Each place on the Earth's surface has its own "local" time, mean and apparent, which is the same at all points in the same longitude, and which differs from points east and west of the place by four minutes for each degree of difference of longitude.

It was stated above that the Earth rotates on its axis with great regularity ; this rotation with reference to the stars provides indeed a time-keeper of great perfection, limited only, so far as is known, by a small periodic shifting of the axis of rotation within an area at the surface a few yards across, and by the very small secular retardation already referred to. From the study of ancient records of eclipses of the Sun and Moon by Babylonian and Greek historians and astronomers, by calculation from the recorded times of day and magnitudes of these eclipses and from the places where they were said to have occurred, this slowing down of the Earth's rotation has been detected and measured. The estimate made by Dr. J. K. Fotheringham of the amount of this retardation, following on the researches of Dr. P. H. Cowell, is such that a clock keeping accurate time with the Earth at any moment and continuing at the same rate will be 0·3 seconds fast at the end of a century, four times this in two centuries, nine times or say two and a half seconds fast after three centuries, and after two thousand years the clock would be two minutes fast. This retardation seems very little,



From "Time and Clocks," by H. H. Cunynghame.
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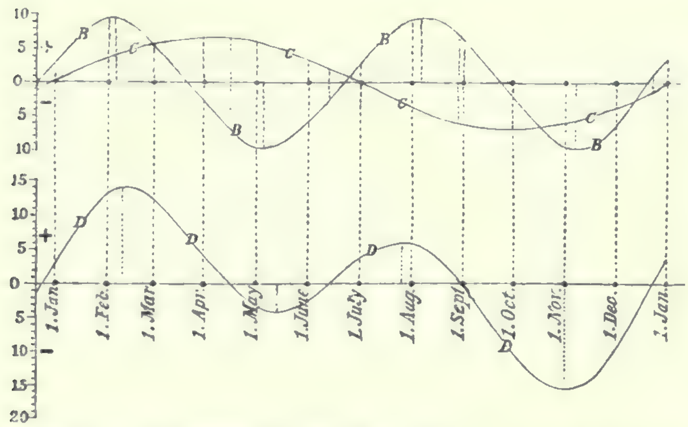
CLEPSYDRA, OR WATER-CLOCK.

The vessel on the right is maintained full and overflowing. From it water drips slowly by the small opening P into the vessel A. As the water-level rises in A the floating figure B rises, and the index C moves over the scale on the drum D. When the float reaches its highest point it moves the wheel E through one tooth by the pawl F, the water flows over the siphon G and empties A, and a new day begins. The wheel E has 365 teeth, so that the drum D turns once round in a year. The lines on the drum give readings in temporary or seasonal hours—in summer twelve long daylight hours and twelve short night hours ; in winter the reverse.

but the Earth is a massive body and to slow it even this amount requires an expenditure of energy every year equivalent to the raising of nearly three million million tons a mile high ; or, to put the matter in another way, to retard the Earth to this extent involves the continuous expenditure of about two thousand million horse-power. This slowing has always been attributed to the friction of the tides caused by the Moon and Sun in the surface water and solid matter of the Earth. It has been shown lately by Prof. G. I. Taylor and Dr. Harold Jeffreys that the effect of the tides in the solid rocks and of the water in open seas is inconsiderable, and that practically the whole retardation can be accounted for by the flow of the tides in shallow land-locked seas and bays such as the Irish Sea.

The standard of time is the Earth's rotation with reference to the heavens. A time-keeper, however regular, requires a hand and a dial in order to be read. The hand or index used in all accurate determinations of time is the transit instrument, a telescope set with great precision in the meridian, and this will be considered later. The dial is supplied by the stars, but the zero of the dial is no one star nor a fixed point among the stars, but the First Point of Aries, as it is called ; or the spring equinoctial point. When this is on the meridian of any place a sidereal clock at that place should read 0 hours 0 minutes 0 seconds. The First Point of Aries, so named because at its naming it was in the constellation Aries, though it has since moved into Pisces. is that point on the ecliptic at which the Sun arrives at the moment of the spring equinox on the 21 March. Owing to precession the equinoctial point moves slowly backwards, that is in a westerly direction, meeting the Sun before he has quite completed his circuit of the stars. A tropical year, then, from spring equinox to spring equinox, is shorter than a sidereal year by about twenty minutes. The precession of the equinoxes was discovered by Hipparchus. The points make a complete circuit of the ecliptic in about 26,000 years.



From "A Treatise on Astronomy," by Hugh Godfray.
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EQUATION OF TIME.

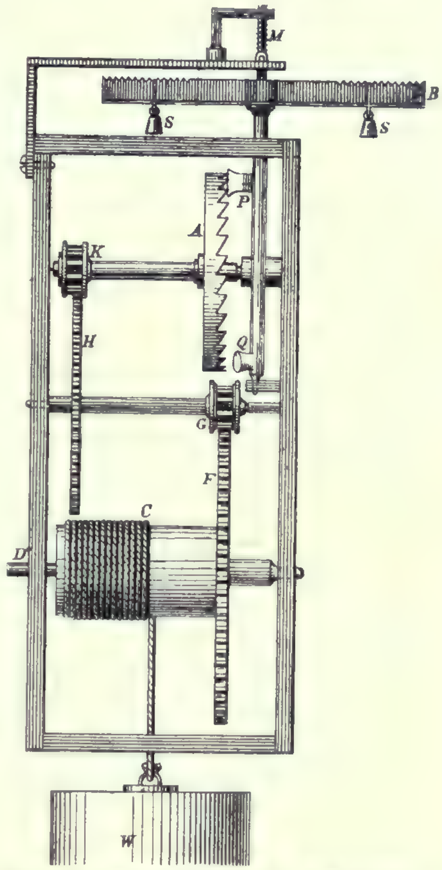
The scale to the left is in minutes ; + means Sun after clock, — Sun before clock. The curve B represents the effect due to the obliquity of the ecliptic ; the curve C that due to the ellipticity of the Earth's orbit. D is the combined effect of B and C. This equation is the correction to be applied to the apparent time given by a sun-dial to obtain mean solar or clock time.

The solar day and the tropical year are the two periods of most obvious practical interest to man, determining as they do the alternation of light and darkness and the succession of the seasons. Records extending over hundreds of years have enabled astronomers to compute with great accuracy their relative values. The Chaldeans reckoned the year to contain 365¼ days, and this estimate we now know to be about eleven and a quarter minutes too much. Hipparchus measured the year in terms of days with an error of only about five minutes. It was upon such knowledge that Julius Cæsar, advised by the Alexandrian astronomer Sosigenes, based his calendar. This was not superseded until the Sixteenth Century, when Pope Gregory XIII introduced his reform based on later knowledge. The Gregorian Calendar is so well planned that it is destined to maintain the adjustment of the spring equinox to the 21 March for thousands of years without further correction.

This New Style was not introduced into England till the year 1752, and the cataclysm of the Great War was required to force its adoption upon Russia, Greece and other eastern States and upon the Orthodox Church. The length of the tropical year in mean solar days is now known with an accuracy of a thousandth part of a second. Since the number of sidereal

days in a year is exactly one more than the number of solar days it follows that the relation of the year to the sidereal day is known with an equal degree of accuracy, and also that of the sidereal day to the mean solar day. The sidereal time at mean noon at Greenwich is calculated for every day in the year and published in the Nautical Almanac. It may be pointed out as of some theoretical interest that the sidereal time there given is not, as is perhaps thought by some, a uniformly flowing time as is mean solar time. As stated above, the zero of sidereal time is determined by the position of the spring equinoctial point, which moves by precession along the ecliptic. Owing to the phenomenon called nutation this point does not move with a uniform velocity and the sidereal time as given in the Nautical Almanac makes allowance for this want of uniformity. No clock showing sidereal time has ever yet been designed, or has any immediate prospect of being designed, of such accuracy as to be capable of detecting this want of uniformity.

The standard time at all observatories is determined daily when the conditions of the sky are favourable, by observation of the stars with the transit instrument. The method of doing this will be considered later. The sidereal time so obtained is converted into mean solar time for ordinary civil purposes by tables of the sidereal time at noon. The time can be obtained with greater accuracy from observation of the stars than by direct observation of the Sun, and this method has the further advantage that favourable opportunities as regards the conditions of the sky can be made use of at any time of day or night.



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EARLY CLOCK MOVEMENT.

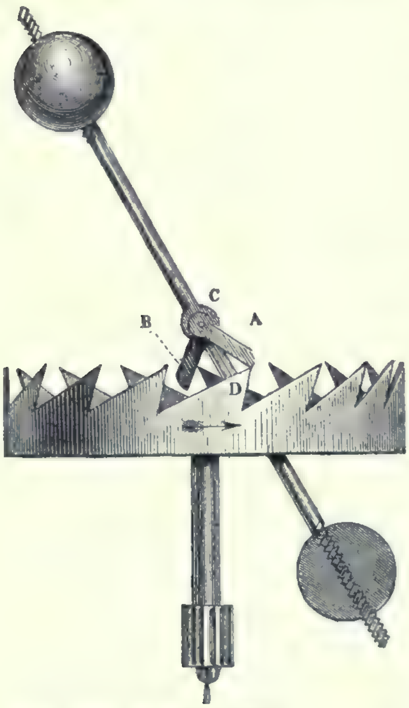
B, the balance with adjustable weights S S, M Q the balance staff or verge, P and Q the pallets engaging with the teeth of the crown-wheel A, K and G lantern pinions of cylindrical rods between two side pieces. Before the invention of the pendulum all clocks were made with such a balance and with this verge escapement.

The development of methods of accurate determination of time and of accurate time-keeping have progressed together. Correct determination and correct measuring are mutually dependent. Geared mechanism was doubtless known from early times, but the first application to the measuring of time seems to have been made at the end of the Thirteenth Century. We hear that an instrument for striking the hour on bells was erected in a tower at Westminster in 1288 for giving the time to the Courts of Law. This was correctly called a clock (French *cloche;* German *glocke*—a bell). During the next hundred years several are known to have been erected on the cathedrals of this country and on the Continent. In addition to striking the hour on bells they sometimes showed various astronomical phenomena. In those cases where these early clocks indicated the time by a hand on a dial there was one only—the hour hand. This was made to move in the direction in which the shadow of the gnomon moved on a horizontal sun-dial. The clock was in fact a mechanical sun-dial and the " clock-wise " direction of the motion of the hands of all time-keepers remains as a record that clocks were evolved in the northern hemisphere.

The designing of time-keepers depends on the provision of (1) a body vibrating with a constant period, of (2) a means of maintaining the vibration against friction and air-resistance, and of (3) a means of counting the vibrations and of recording on a dial. The efficiency of the time-keeper will depend on the degree with which (2) the maintaining, and (3) the counting, are effected without

disturbing the period of (1). Since some degree of disturbance is inevitable it is necessary that the vibrating body shall have the property known as isochronism. This property will now be explained.

If a thin steel rod be clamped by one end in a vice and a weight be attached to the free end, this weight will tend to take up a neutral position about which it will vibrate if disturbed and at which, after a number of excursions to and fro, it will eventually come to rest. It is a property of such a rod that when forcibly moved out of its neutral position the force tending to restore it is proportional to the distance moved. When, as in this case, the recovering force is proportional to the displacement, the period of vibration is constant and independent of the amplitude of the vibration. A tuning fork is another instance of this, as is shown by the note given out maintaining its constant pitch as it dies away. Such a vibration is said to be isochronous and it is essential that the vibrating system governing a time-keeper shall obey this law.



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EARLY CLOCK BALANCE AND VERGE
The governing mechanism of the first clocks. The tooth D of the crown-wheel has lifted the pallet A and is about to escape. When this has happened an opposite tooth will bear upon the pallet B and escape in its turn. Thus the balance is driven backwards and forwards. The arbor or rod centred at C and carrying the balance and two pallets was called the verge. As the period of vibration is directly dependent on the driving force of the wheel, the arrangement is defective. The time-keeping was greatly improved when a pendulum was substituted for the balance.

Till the Seventeenth Century clocks were controlled by a balance consisting of a bar weighted at each end and attached at its middle point to a pivotted spindle or verge. Pallets attached at two points to the verge engaged alternately with the upright teeth of a wheel shaped like a crown, a tooth escaping alternately on one side and on the other across a diameter of the wheel. In this way the balance was forced to rotate backwards and forwards with the verge, the driving force of the train of wheels giving energy to the balance and the balance controlling the movement of the train (*see* figure on this page). The law of isochronism was not obeyed in this system and such clocks were poor time-keepers in consequence, the rate varying with the force of the train which was not constant. A clock of this character, said to have been made in 1348, and formerly in Dover Castle, is still kept in working order in the Science Museum, South Kensington. These early church clocks were, except in their governing mechanism, very like the commoner clock of to-day. A weight, often a large stone, drove the train of wheels by a rope wound round a cylindrical barrel, to which was attached the slowest or "great" wheel. This drove the centre wheel and this through an intermediate wheel drove the crown or 'scape wheel (*see* figure on page 695). The first great advance in clocks was the application of the pendulum as the controlling system. According to tradition the isochronism of the pendulum was first discovered by Galileo when watching the great chandelier hanging from the roof of the cathedral at Pisa. He noticed that the period of swing remained constant as the extent of swing became less. Huyghens treated the matter theoretically and showed the suitability of the pendulum for the government of a clock. It was not, then, until the Seventeenth Century that clocks were made in which the old balance was replaced by a pendulum. From that time to the present day progress has been rather in respect of detail than of principle and with the full history of the improvements it is impossible to deal here. A few points only can be referred to.

In 1680 Clement of London substituted the anchor escapement with a flat 'scape wheel for the crown wheel and verge (*see* top figure on page 697), and early in the Eighteenth Century Graham introduced an improvement that is comparable with the application of the pendulum in its importance in the history of good time-keeping. He altered the form of the bearing surfaces of the pallets and

the shape of the teeth of the 'scape wheel in such a way that the pendulum was free from the force of the train except for a short distance on each side of its vertical position (*see* lower figure on this page). Even to-day, with few exceptions, the Graham dead-beat escapement is applied to all clocks where really good time-keeping is demanded. Graham, for this and other improvements in the making of clocks, was honoured with burial in Westminster Abbey. In the meantime advances were being made in the workmanship of the wheel train and in the cutting of the teeth so as to give a more constant driving impulse to the pendulum, and various forms of compensation were being introduced to eliminate as far as possible the effects of changes of temperature upon the free period of its swing (*see* figures on page 700 and page 701 (top)).

About the end of the Fifteenth Century flat steel coiled springs were substituted for the falling weight as the driving power where portability was a consideration, and in the Sixteenth Century small clocks were made that could be carried about (*see* top figure on page 702). These were poor time-keepers until the "hair spring" or "balance spring" was invented by Dr. Hooke about 1664 and was applied to control the vibration of the balance. The balance then became a more nearly isochronous governor and was a fair substitute for the pendulum for portable time-pieces. About the year 1770 Thomas Mudge applied the idea of Graham's dead-beat escapement to watches in the form known as the "lever," and about the same time Le Roy, of Paris, invented the "detached" chronometer escapement (*see* figures on pp. 702 and 704). The lever escapement, with improved design, is still universally applied to pocket watches of all but the cheapest kinds, as is the detached escapement always used for ships' chronometers. The advantage to good time-keeping of the dead-beat applied to clocks, and the lever and detached escapements applied to watches and chronometers, is the freedom allowed to the pendulum and balance respectively, so that their isochronous properties may have better effect. As Harrison said in a description of one of his time-keepers to be dealt

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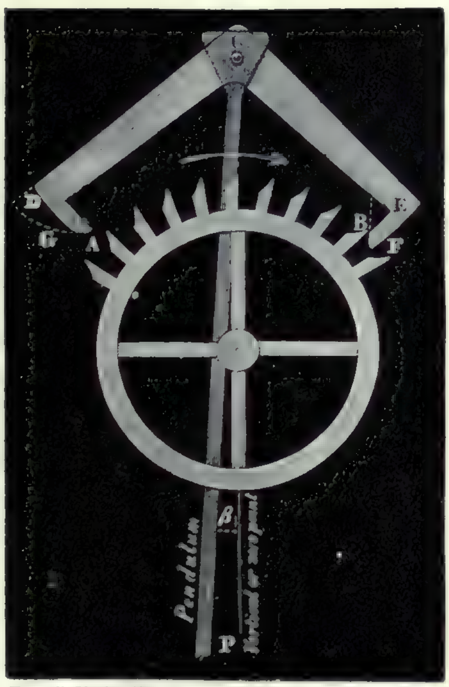
ANCHOR RECOIL ESCAPEMENT.

Similar in principle to the verge (*see* figures on pages 695 and 696), but a flat wheel has taken the place of the crown-wheel, and the two pallets move in the same plane. The advantage over the verge is that a smaller swing of the pendulum is required to allow the teeth to escape. In both these escapements the pendulum is never free from the driving force of the train of wheels which recoils after the escape of each tooth. Any inconstancy of the force of the train affects, therefore, the period of swing.



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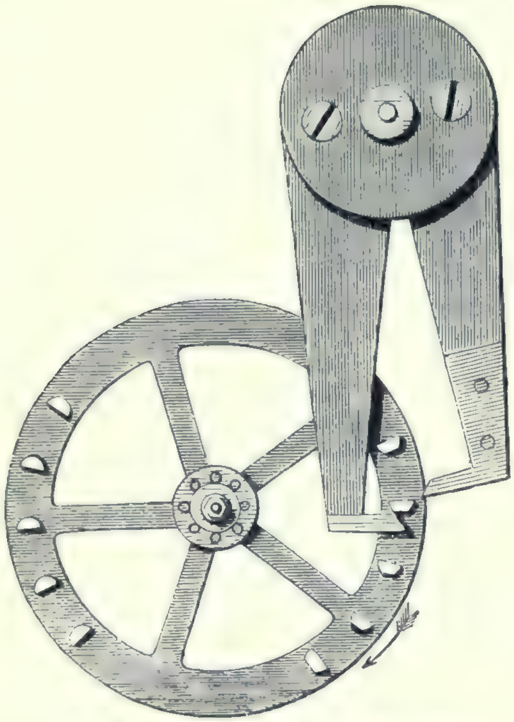
GRAHAM'S DEAD-BEAT ESCAPEMENT.

Still almost universally applied to clocks having a pretension to accuracy. It differs from the Recoil (*see* upper figure on this page) in having the portions G D and B E cut away, leaving the surfaces G D and B E arcs of circles about the centre C. Except, then, while the pendulum is near its vertical position and the points of the teeth are sliding down the slopes of the pallets at A and B, giving their impulse to the pendulum, the latter is free from the force of the train except as regards friction. With this escapement there is no recoil, hence the name. [In the figure too much space is shown at A].



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PIN-WHEEL ESCAPEMENT.
A modification of Graham's dead-beat escapement frequently used for turret clocks.

with later, "the less the wheels have to do with the balance the better." With these inventions progress seemed to have come to an end, except for improvements of detail, and time measuring was equal to the demands put upon it by the accuracy of time determination.

Any interference with the freedom of vibration of an isochronous system by the addition of energy, or by its subtraction, in any part of the path of the body except at the neutral position alters the period of its vibration. Hence it is important that the impulse shall be given to the pendulum or balance at a part of the swing confined as nearly as possible to this position. Further, any work the pendulum or balance is required to do in the way of unlocking the escapement or of overcoming friction should, for the same reason, be done near the neutral position. The errors of rate due to want of perfection of design in those respects are called escapement errors.

It has been assumed so far that the pendulum is strictly isochronous. This is not the case, as was shown long ago by Huyghens. If T_o is the half period when the amplitude is very small, and if T is the half period when the same amplitude is α degrees, then $T = (1 + 0{\cdot}0000194\alpha^2)T_o$. As the amplitude increases the period of swing lengthens by an increment of time proportional to the square of the amplitude. To take a concrete case, if a seconds pendulum is keeping correct time when its complete arc (twice the semi-amplitude) is three degrees, a usual amount for a good clock, it will lose nearly a tenth of a second a day if by a change of impulse its arc increases by only two minutes of angle. Such variations of rate are said to be due to circular error. It follows then that for good time-keeping the swing of a pendulum should be small within certain limits, and the impulse should be constant. In practice, changes in the driving impulse are due to various causes, including changes in the force of the main spring where one is used, to imperfection in the gearing of the wheels of the train and to conditions of lubrication. A method of eliminating the effect of these changes often made use of is to impel the pendulum directly by a lever acted on only by gravity. The clock train raises the lever at the right moment to a position from which the pendulum in its motion releases it. The lever then falls under gravity with the pendulum, giving it a constant impulse. Perhaps the most notable gravity escapement is the "double three-legged," a modification by E. Beckett Denison, afterwards Lord Grimthorpe, of a form designed by Bloxham (*see* figure on page 699). This was first applied to the great Westminster Clock where it has proved astonishingly successful. It is unsuited for small clocks.

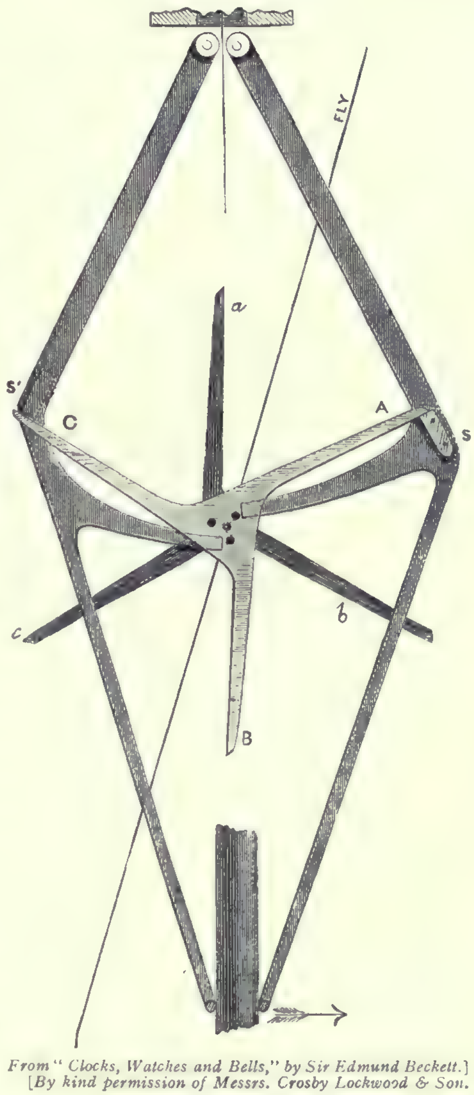
The balance spring of a watch requires to be curved according to certain rules in order to be strictly isochronous. Breguet and Arnold at the end of the Eighteenth Century arrived empirically at approximations to the correct curves which were not fully understood theoretically for another hundred years. With watches and chronometers, then, it is also important that the driving impulse shall be as constant as possible in order to reduce escapement errors and errors due to want of isochronism.

With improvements of late years in the methods of observing for time determination new demands are arising. The clocks made by Dr. Riefler, of Munich, with his own escapement, have for some years held the field. Now new methods of time-keeping are being studied in which the pendulum is almost entirely free, in which there is often no clock train or escapement at all, but where by the use of electric

contacts the pendulum registers its vibrations and receives its impulses with the very minimum of disturbance. The impulse is given generally by a gravity lever raised by an electro-magnet and released by an electric contact. With these precision clocks the pendulum is now generally made of a nickel-steel alloy of small coefficient of expansion with temperature. This alloy was discovered and investigated by Dr. C. E. Guillaume and named by him "invar." In order to eliminate the disturbing effects of changes of density of the air with changes of barometric pressure the pendulum is suspended in an air-tight case, and to reduce temperature effects is placed in a room maintained at a constant temperature. Under these circumstances variations of rate may amount to an average of only one-fiftieth of a second a day.

The subject of navigation is so intimately connected with the methods of determining and measuring time that some consideration must here be given to it.

Until the Fifteenth Century sea voyages were almost entirely confined to the coasts. Seamen were guided by sight of land and by dead reckonings based on rough estimates. The magnetic compass was known in Europe in the Fourteenth Century but was not generally in use at sea for more than a hundred years afterwards. There had been no substantial improvement in navigation for thousands of years, and to go far out of sight of land was a serious venture. Latitude could be roughly estimated by noting the altitude above the horizon of the pole star. The instrument used for this purpose was the cross-staff, consisting of a long wooden rod upon which slid a cross-piece. There were pin-hole sights at the near end of the rod and at both ends of the cross-piece, and an observation consisted in placing the eye at the former and sliding the cross-piece along until the two objects, or the heavenly body and the sea horizon, coincided respectively with the two sights on the cross-bar. The required angle was then read off on the body of the rod, which was divided into degrees. In the Fifteenth Century Prince Henry the Navigator and John II (1481–95) of Portugal tried to improve navigation and caused more accurate calculations to be made of the Sun's declination, and the results to be published in tables whereby the latitude at sea could be determined from the altitude of the Sun. John also introduced the astrolabe, as more convenient for measuring altitudes. This instrument had been known from early times. A simple form consisted of a heavy metal disc suspended by a ring at the upper edge. Pivotted at its centre was a pointer extending across a diameter and carrying a pin-hole sight at each end. The pointer was moved until the sights were in line with the Sun or other heavenly body when the disc was suspended and at rest. A scale of degrees round the edge then gave the altitude of the body. As yet there was no means of measuring



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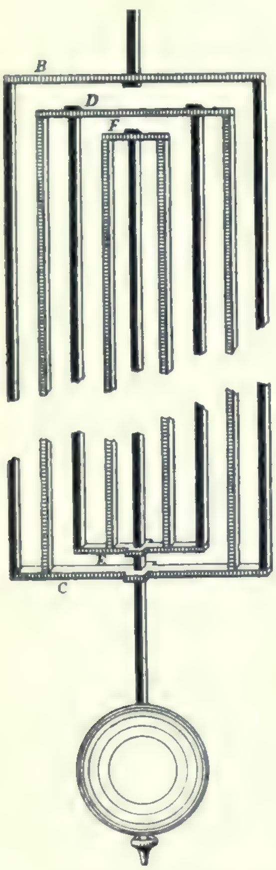
DOUBLE THREE-LEGGED GRAVITY ESCAPEMENT.

A modification by E. Beckett Denison (Lord Grimthorpe) of an escapement by Bloxham, and adopted by the former for the Westminster clock. The pendulum is driven by the two gravity levers pivotted at the top of the figure near the point of bending of the pendulum suspension spring. As the pendulum rises, it picks up and lifts one lever, the double three-legged wheel is thereby unlocked and lifts the other lever. The impulse given to the pendulum is independent of the clock train and is due to the fall of the levers under gravity from their higher positions to their lower.

distance travelled nor of determining longitude. With these difficulties in mind it is astonishing to read of the doings of the great navigators of the Fifteenth and Sixteenth Centuries. The seaman, when he had once lost sight of land, depended entirely on the roughest means of estimating "the way of the ship," and if this dead reckoning was miscalculated or lost he had no method of knowing where he was. Columbus and Cabot sailed into the unknown when they crossed the Atlantic at the end of the Fifteenth Century. So incapable of determining longitude was he, that Columbus, when he arrived at the islands off Central America, thought he was among the islands to the East of India; the natives were called Indians and the islands took the name of the West Indies. Between 1519 and 1522 Magellan sailed round the world by way of Cape Horn, not only crossing the Atlantic but also the Pacific. By the end of the Sixteenth Century there was a rage for ocean exploration and merchant adventuring, as the names of Drake, Willoughby, Frobisher and Hudson will recall to mind.



From "A Treatise on Astronomy," by Hugh Godfray.
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A METHOD OF PENDULUM COMPENSATION.

Harrison's Gridiron Pendulum. The black rods are of steel, the shaded rods of brass. The latter having a higher co-efficient of expansion with temperature than steel, the effective length of the pendulum is maintained constant. Still rarely to be seen on old clocks.

During these centuries the production of maps and charts was making progress and at the end of the Sixteenth Mercator's projection, so invaluable to navigators, was in process of development. Davis's quadrant or back-staff came into use as an improvement on the cross-staff; the variation of the compass was being studied and better tables of the declination of the Sun and stars were being calculated. Then, about 1624, the Dutchman's log for measuring the ship's way (described on page **690**) began to be adopted, but Norwood, in his work on navigation, "The Seaman's Practice," published in 1637, could still write, "as there is no means of discovering the longitude a seaman must trust to his reckoning."

In the early Seventeenth Century ocean voyaging was becoming so general that the want of a method of determining longitude was seriously felt. If the seaman could only have means of knowing the time at any place marked on maps and whose longitude was known, this knowledge, combined with comparatively easy means of determining his local time, would have given him his longitude at once. The determination of time by the method of "equal altitudes" of the Sun which had been practised by the Arabs hundreds of years before the present era, was introduced into Europe about the middle of the Fifteenth Century and was much in use in the Seventeenth. This consisted of noting the two moments at which the Sun attained some convenient altitude above the horizon, respectively before and after crossing the meridian. The moment half-way between these events was taken as noon (*see* lower figure of page **704**). The time so obtained was apparent noon and by applying the equation of time mean noon would be known. The difference between this and the mean time at the same instant at some place of known longitude, if such had been obtainable, would have given the ship's longitude by allowing fifteen degrees east or west for each hour the ship's time was before or after the time of the known place.

After the discovery of Jupiter's satellites by Galileo, about 1610, it was proposed that the times of eclipses of these bodies should be calculated and published in advance in an almanac for seamen. It would, however, be difficult to make use of a telescope with a sufficiently large magnification on the deck of a ship and, moreover, these eclipses are not sufficiently definite in time to serve this purpose. It had also been suggested by Werner as early as 1514 that the movement of the Moon among the stars would be a valuable method of determining absolute time and thence of longitude at sea, but the places of the stars and the motion of the Moon were not sufficiently known

then, and observing instruments were not of sufficient precision.

It was under these circumstances that Le Sieur de St. Pierre brought to King Charles II a proposal that tables of the places of stars and of the motions of the Moon should be made and published in an almanac for the use of sailors. Charles II, who seems to have had more enlightenment than is generally attributed to him, was pleased with the idea and referred the proposal to the Royal Society, which had lately been founded (1662). John Flamsteed, who was known to the Fellows of the Society as a brilliant young mathematician, was selected to report on the matter. He reported that the proposal was a good one but was impracticable owing to the want of sufficiently accurate knowledge of the places of the stars and of the motion of the Moon. Tycho's catalogue of stars, the best available, was not good enough for the purpose intended. Charles thereupon (to quote the terms of the Royal Warrant of 1675, from Mr. E. Walter Maunder's "History of the Royal Observatory, Greenwich," from which many of these facts are taken) commanded Flamsteed "to apply himself with the most exact care and diligence to the Rectifying the Tables of the motion of the Heavens and the Places of the fixed Stars so as to find out the so-much-desired Longitude of places for the perfecting the Art of Navigation." A few months later a further warrant ordered that Sir Christopher Wren should build "a small observatory" within "our park at Greenwich" at a cost of not more than £500. Flamsteed was then installed as the first Astronomer Royal at a salary of £100 a year, out of which he was to provide himself with the necessary instruments. He did apply himself with care and diligence and his catalogue of stars made at Greenwich was a great advance. Miss Agnes Clarke quotes Delambre as saying "The establishment [at Greenwich] was indeed absolutely without a rival. Systematic observations of Sun, Moon, stars and planets were during the whole of the Eighteenth Century made only at Greenwich."

From "A Treatise on Astronomy," by Hugh Godfray.
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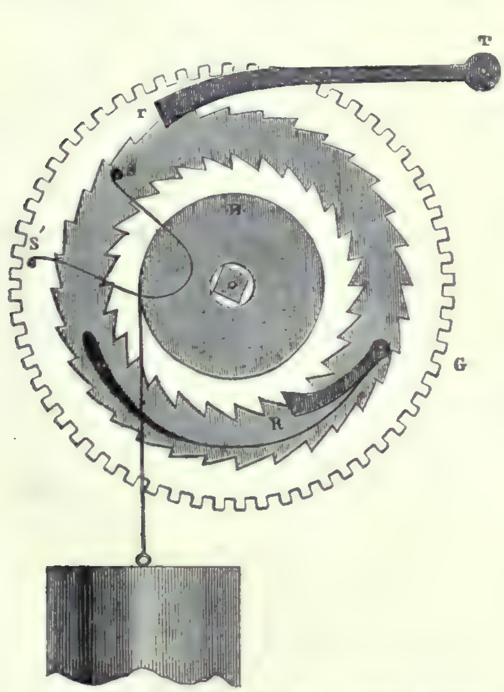
GRAHAM'S MERCURY COMPENSATION.

At the end of the steel rod is a stirrup carrying a glass jar of mercury, forming the bob of the pendulum. The mercury having a high coefficient of expansion rises in the jar with increase of temperature, compensating for the lengthening of the rod. Still in common use, but being superseded by pendulum rods of invar nickel-steel.



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MAINTAINING MECHANISM.

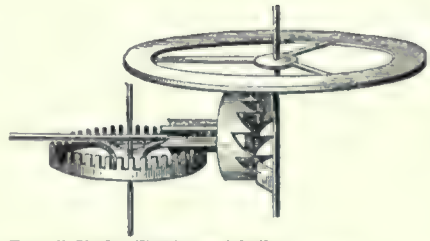
A simple ingenious contrivance invented by Harrison for maintaining the driving power of the clock or watch while it is being wound. The smaller ratchet-wheel attached to the barrel B drives the larger ratchet-wheel by the pawl R, which in turn drives the great wheel G by the spring S S′. On the barrel being turned by the winding key to the right, the larger ratchet-wheel is prevented from following the barrel to the right by the pawl r and the movement continues to be driven by the spring S S′. Used on all good clocks, watches and chronometers.

It may here be mentioned that about the year 1700 Roemer invented the transit instrument by which time could be determined by transits across the meridian, but at sea the only instruments yet available for measuring angles and altitudes and for determining local time were the astrolabes and various forms of quadrant which involved the necessity of looking in two directions at once. It was not till about 1731 that Hadley introduced his quadrant, the forerunner of the present sextant, in which by the use of a mirror the image of one object could be thrown into coincidence with the other and the angle between them measured with accuracy.

In 1714, "Commissioners for the discovery of longitude at sea," forming the Board of Longitude, were appointed with power to expend money and award

prizes. Flamsteed died in 1719 and was succeeded by Halley, who in 1731 showed that it was impossible then to find the correct longitude by the Moon. He hoped in a few years to compute the Moon's position within two minutes of time, from which he thought longitude could be found within sixty nautical miles at the equator and within forty-five miles in the English Channel.

In the meantime Newton was at work on his theories of motion and gravitation. He had applied to Flamsteed, who was little interested in theory, for places and elements of planetary orbits with which to test his theory of gravitation. Ultimately, in 1748, Mayer published his lunar tables based on the foundation laid by Newton. During these seventy years we see theory and observation in co-operation, though by no means always on friendly terms, in building up the material it was expected would aid the navigator.



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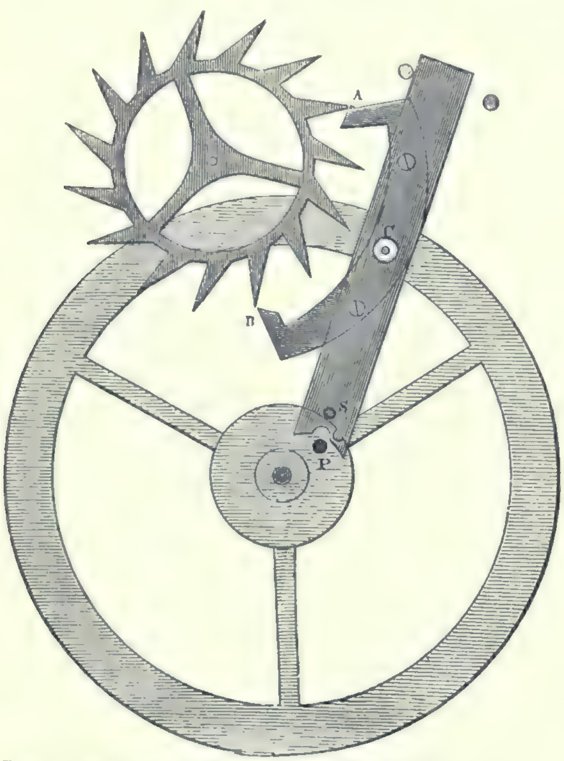
VERGE ESCAPEMENT.

A small form of the verge shown on page 696, adapted for pocket instruments. Watches were all provided with this defective control until Robert Hooke invented the balance spring about 1664. Watches with balance spring but retaining this "verge" escapement were in common use till the early Nineteenth Century, and are said still to be made. Harrison's historic sea-watch was made with an improved verge, the pallets being shaped so as to be nearly dead-beat.



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LEVER ESCAPEMENT.

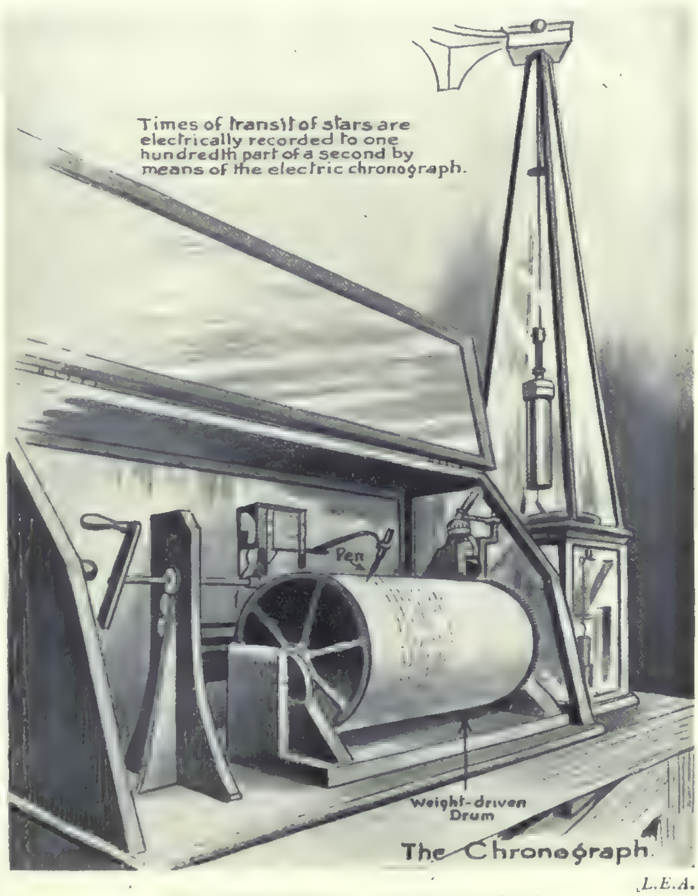
Invented by Mudge, apprentice to Graham, about 1770, and now universally used in good pocket watches, and in portable clocks, including those of the cheapest description. The action of escape wheel and pallets is the same as with Graham's dead-beat pendulum escapement (*see* lower fig. page 697). In the figure the balance is moving to the right, quite free and controlled only by the balance spring. On its return the pin P will enter the notch of the lever S C, pushing it to the left, unlocking the tooth A which, sliding down the impulse slope of the pallet, will press the lever to the left, which will then give a push to the pin P, giving an impulse to the balance. The merit of the escapement consists in the freedom of the balance, except about its neutral position.

Prizes had been offered by the Board of Longitude for a method of determining longitude at sea. £10,000 was to be awarded for a determination within sixty miles, £15,000 within forty miles, and £20,000 if within thirty miles, and the test was to be made on a voyage of a ship to the West Indies and back. Portable timepieces were continually being improved and it was thought possible that if Greenwich time of sufficient accuracy could be carried on ships it would supply a better method of determining longitude than could be provided by lunar methods.

The improved escapements of Mudge and Le Roy had not yet been invented, but the outstanding defect of watches at the time was the great variation of rate with temperature. John Harrison, a carpenter and watch repairer of Yorkshire, had been studying a method of remedying this, both with pendulum clocks and watches, depending on the different expansions of two metals (*see* figure on page 700). He came to London and in 1735 submitted a machine embodying this and other inventions, for the purpose of claiming the reward offered. Halley gave him support, but the story is a long one of Harrison's endeavours to obtain recognition of his watches by the authorities, and of the opposition he met with from Nevil Maskelyne and others who were more interested in lunar distances as in their opinion the more promising solution.

Eventually, in 1761, one of his watches was taken to the West Indies and back, a voyage of five months, during which the accumulated error was 1 minute 54·5 seconds, corresponding to an error of longitude of eighteen miles at the latitude of Portsmouth, well within the limits laid down by the Board. He obtained the completion of his reward of £20,000 in 1773, three years only before his death (*see* figure on page 705). Fine watch and clock making was then making great progress in the hands of Harrison, Mudge, Earnshaw and Arnold in England, and of Berthoud, Le Roy and others in Paris. The ship's watch then took the name of chronometer.

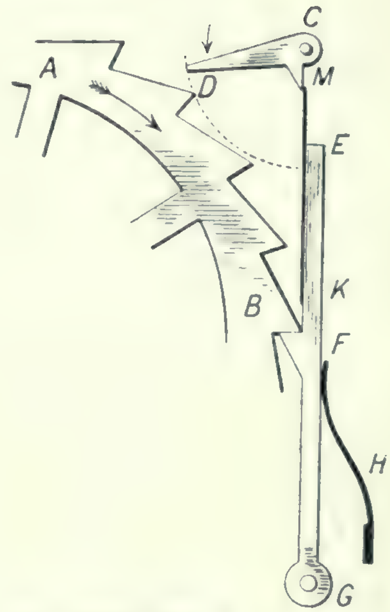
As Harrison's sea-watch which underwent this trial is the most famous that has ever been made, a few words of description will not be out of place. In the course of fifty years of trial, strenuous labour and patient thought given to improvements, this was the fourth he had made to embody his original ideas. It contained the maintaining power invented by himself (*see* figure, page 701), the well-known fusee for rendering the effective force of the spring constant and his "compensation curb," perhaps the most important factor towards rendering his instrument efficient. This last consisted of a means of automatically altering the effective length of the balance spring with temperature. A compound bar of brass and steel carrying the curb-pins which determined the effective length of the spring moved these pins with change of temperature, thereby compensating for change of rigidity of the spring. The escapement, which gave five ticks to the second, was the old verge and crown wheel, but so greatly improved as to remove the grave defects of the old escapement. The pallets, of diamond, were entirely altered in form so as to be nearly dead-beat. The escapement, moreover, instead of being driven directly by the wheel-train was driven by a spring remontoire which was rewound by the train every seven and a half seconds. Seven sets of holes were jewelled with rubies and diamond end-stones. The instrument was enclosed in a detachable outer case of 5·2 inches in width and shaped like a pocket watch, and was not suspended in gimbals. Harrison was awarded the Copley medal, the highest honour in the gift of the Royal Society. He refused Fellowship of the Society in favour of his son William.



THE GREENWICH CHRONOGRAPH.
The drum is driven by a weight and controlled by the conical pendulum. With each alternate beat of the standard sidereal clock the pen makes a kick, breaking the continuity of the helical line on the drum. The travelling wire micrometer in the eyepiece of the transit circle automatically records the progress of a star across the meridian by a kick of the same pen. The time of transit can thus be read to about one-hundredth of a second.

Nevil Maskelyne, on a voyage to St. Helena in 1761 to observe the Transit of Venus, made use of Mayer's tables of lunar distances, and measured altitudes by Hadley's quadrant. The longitudes he so found were within a little more than one degree. He is quoted as saying that from this experience he could show that longitude could be found at sea from lunar observations by good

observers, within one and a half degrees of the truth. He recommended this method to the Admiralty and afterwards, in 1767, having in the meantime become the fifth Astronomer Royal, he issued the first Nautical Almanac containing tables of lunar distances. These were published in every year's issue until 1906, since which year they have been omitted as it was found they were seldom used by seamen. The lunar distance method of finding Greenwich time and thence longitude was soon superseded as chronometers were perfected. Though Harrison was the pioneer, and first showed that the problem of longitude could be solved by a marine timekeeper, the father of the modern chronometer was Pierre Le Roy, a French contemporary of Harrison. Le Roy placed the means of temperature compensation in the balance itself, invented the detached escapement (*see* top figure on this page) and suspended his chronometers on gimbals in a box, all of which improvements have been continued to the present day. Within thirty or forty years of the first publication of lunar distances in the Nautical Almanac chronometers were being made on a commercial scale by Arnold and Earnshaw showing continually better performances, and the method of lunars went out of use. Navigation is now dependent on the chronometer, one or more instruments being carried on every seagoing ship. With the use of wireless time signals from many stations around the world, ships' chronometers can now be checked and rated at sea, and all difficulties in obtaining exact longitude are at an end. Wireless signals also enable differences of longitude of observatories to be found with great accuracy, and are invaluable to travellers for learning their positions in remote or inaccessible places.



From "Time and Clocks," by H. H. Cunynghame. [*By kind permission of Messrs. Constable & Co., Ltd.*

THE DETACHED, OR CHRONOMETER ESCAPEMENT.

Now used on all ships' chronometers. The balance staff C carries the impulse pallet D C. The escape wheel A B is locked by the detent G E. As the balance returns in the direction of the arrow the escape wheel is unlocked by the pallet M, the tooth at D engages with the impulse pallet D C, giving the balance a push and the detent G E falls back ready again to lock the escape wheel. On the return of the balance the pallet M passes the light spring M K. The balance is entirely free except when near its neutral position—the great merit of the escapement.

Some consideration will now be given to the way in which mean time is determined day by day from the steady march of the stars across the sky. The methods employed at the Royal Observatory, Greenwich, will be taken as indicative of those followed at time-determining observatories generally.

The positions of the stars on the celestial sphere are recorded in an analogous way to the positions of places on the Earth's surface. The poles of the celestial sphere are the points at which the Earth's axis would pierce the sphere if extended, and the equator is the great circle in the heavens in the plane of the Earth's equator. A star's position is recorded by its declination or angular distance north or south of the equator, and by its right ascension or distance east of the spring equinoctial point. Declination then is exactly analogous to latitude on the Earth, and right ascension is analogous to longitude.

From "Astronomy for All." [*By permission of Messrs. Cassell & Co., Ltd.*

ALTITUDES AT SEA.

The angle W between the Sun or other heavenly body and the horizon is measured by a sextant. In earlier days a cross-staff, an astrolabe, a quarter-staff, a back-staff, or a quadrant, was used for this purpose.

The latter analogy is incomplete in that right ascension is for convenience usually reckoned in time—twenty-four hours to the 360°, and always in the same direction, viz., eastwards right round the sky from $0h.$ to $24h.$ or $0h.$ again. Since, as already stated, sidereal time is zero when the spring equinox is on the meridian of a place, it follows that the sidereal time is the R.A. (right ascension) of any star when this star crosses the meridian. The time given by the sidereal clock at the moment of transit of the meridian by a star should be the same as the R.A. of the star ; the difference is the error of the clock. Now, the stars generally do not maintain their exact positions with regard to one another ; each has its " proper motion " (Latin *proprius*, one's own). In addition to changes due to this, the precession of the equinoctial point brings about a gradual change of R.A. of the stars. Since the time when Charles II commanded Flamsteed, the first Astronomer Royal, to apply himself with the most exact care and diligence to finding the places of the fixed stars, this has been an important part of the regular

JOHN HARRISON'S SEA WATCH.

The legends below read : –

DUPLICATE OF HARRISON'S TIMEKEEPER,
made in 1767–9 by
LARCUM KENDALL.

Used by Capt. James Cook, R.N., 1772–5.
" " " " " 1776–9.
" G. Vancouver 1791.

TIMEKEEPER (NO. 4),
made in 1755–9 by
JOHN HARRISON,
which won in 1764 the reward of
£20,000
offered by the British Government
in 1713.

These watches measure 5·2 inches over all. They are preserved at the Royal Observatory, Greenwich. This beautiful machine of Harrison's, justly the most noted of all time-keepers, was the forerunner of the marine chronometer upon which navigation is dependent.

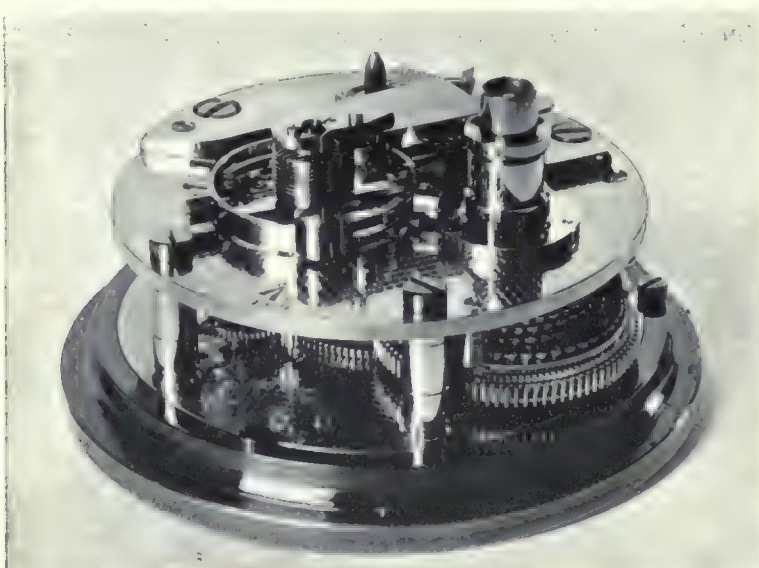
work at the Royal Observatory. In addition to more extensive observations for more general astronomical purposes, a selection of suitable stars, forming a list of " clock stars," are continually studied at Greenwich for their positions and proper motions for the special purpose of time determinations. A list of such stars is given in the Nautical Almanac with their co-ordinates in R.A. and declination calculated for every tenth day of the year and from this list the R.A., from which sidereal time is to be found, can be determined to a small fraction of a second at any time. If then the moment at which one of these stars crossed the meridian at any place could be observed without error, the sidereal time could be learnt from one observation with approximately this degree of accuracy. In practice observation is subject to error, as we shall see.

The transit instrument, by which the moment at which a star crosses the meridian is observed, is a small telescope mounted so as to move accurately in the plane of the meridian. Very special precautions have to be taken to ensure that the axis of movement is truly horizontal ; to correct for

any error of collimation, that is to say for any error of adjustment of the optical axis of the telescope at right angles to the axis of movement ; and to adjust this axis of movement in a truly east-west direction. In the focal plane of the eyepiece of the telescope are generally one horizontal and five or seven equally spaced vertical fine spider threads (*see* figure on page 709). For use at night some means are provided for throwing a light upon these wires so that they may be visibly projected against the dark sky, or the wires may be made visible as dark objects by a general illumination of the field of view. When adjustments have been made the telescope is set to the declination of the star a few minutes before the time of transit. The star is then seen to enter the east or right-hand side of the field of view and to cross each vertical wire in turn. It is the observer's business to note the time by the sidereal clock at which the star's image is bisected by each wire. The mean of these five or seven observations of time by the clock should give the R.A. of the star as given for that day in the Nautical Almanac. If the observations have been correctly made, the difference is the error of the clock.

The instrument used at Greenwich for transit observations is the transit circle, so called because it is provided on each side with a large vertical circle very accurately divided into degrees and sub-divisions for the purpose of taking the declination of the star at the same time as its time of transit (*see* figure on page 708), and thereby of pursuing the original purpose for which the Observatory was established.

The sidereal time given by a properly adjusted transit instrument is the time for that particular longitude. The time determined at Greenwich is Greenwich time. Greenwich time then is fixed by the spot at which the instrument is set up. Halley, who succeeded Flamsteed as Astronomer Royal, erected the first transit instrument, a few years only after its invention by Roemer. This was placed at the north-west corner of the Observatory enclosure, some yards west of the present Greenwich meridian. When the instrument was erected at its present position to the east by Airy in 1851, it could hardly have been thought that this spot was destined to determine permanently the prime meridian of the world, or that the time would come when all longitude and all time would be reckoned from the position of the Greenwich transit circle, as is the case to-day.



From "The Marine Chronometer," by Commander Gould. By courtesy of J. Potter, Esq., London.

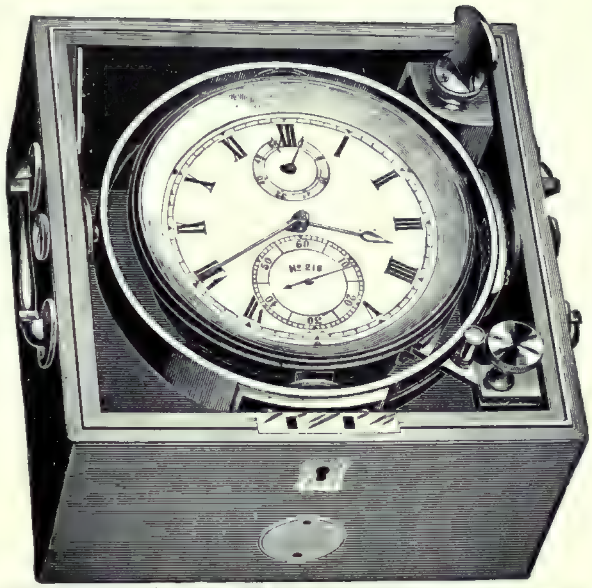
MARINE CHRONOMETER MOVEMENT.

Note the helical balance spring with its ends curved inwards to obtain isochronism. Rise of temperature reduces its rigidity and tends to slow the vibration. To compensate for this, the balance rims are compound, of steel inside and brass outside, and in two halves, each with one end fixed and the other free. Increase of temperature causes the free ends to bend inwards, tending to accelerate the vibration. This compensation is adjusted by shifting the two heavy weights, one of which can be seen in the photograph. Rate is adjusted by turning the two large nuts.

Transit observation made by the old "eye and ear" method consisted in listening to and counting the ticks of the clock and of estimating to one-tenth of a second the time of bisection of the star at each wire. This is considered a rough method to-day, for it is difficult to estimate correctly the division of the interval between the ticks of the clock when the image is exactly bisected by the wire. Different observers have their own personal errors in trying to do this. These personal errors are investigated and a correction applied to the observations of each observer called his "personal equation." Under favourable circumstances a single transit

observation by this old method would be considered good if it could be depended upon to an accuracy of one-quarter of a second.

About the year 1854 a new method of observation was introduced at Greenwich and became common at other observatories. Instead of the observer having to listen to the ticks of the clock, he had to watch the star and press an electric stud with his finger at the instant at which it appeared to him to be bisected by each wire in succession. In an adjoining room is a chronograph, consisting of a cylindrical drum made to revolve with a smooth slow motion on its axis. Around the drum is fixed a sheet of white paper. When a transit observation is to be taken, a pen is brought to bear upon the paper on the drum and is made slowly to travel along the drum by means of a screw. The combined effect of the rotation of the drum and of the transverse motion of the pen is that a helical line is drawn on the paper. This pen is so connected by electric wires with the sidereal clock that with each alternate tick of the clock it is given a sideways kick, breaking the continuity of the line on the drum. The pen is also connected with the stud at the transit circle and is given a similar kick when the stud is pressed. In this way the instant of pressing with the observer's finger was registered on the chronograph alongside the marks made by the clock, and the two could be compared with an accuracy of about one hundredth of a second. From a series of such comparisons each day the error and rate of the clock was estimated day by day. This method was a great improvement on the former eye and ear method, but was not free from incalculable personal error, for different people estimated the instant of bisection of the star differently and had different " reaction times " between seeing the bisection with the eye and pressing the button with the hand. Personal equation with this method was as much as one-quarter of a second, but was fairly constant. Personal error was approximately eliminated when this equation was applied to the observations.



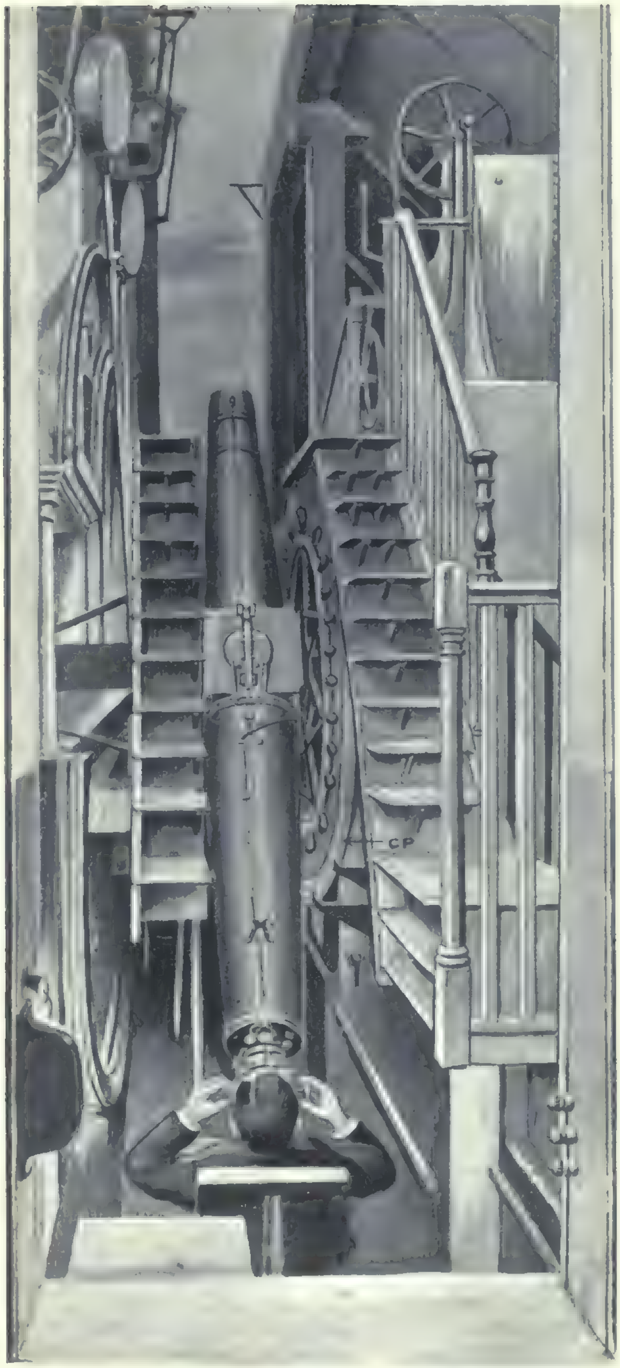
From "Astronomy for All."] [*By permission of Messrs. Cassell & Co., Ltd.*

MODERN SHIPS' CHRONOMETER.

Navigation depends absolutely on Greenwich Mean Time being carried by one or more of these instruments on every sea-going vessel. From altitudes of the Sun or other heavenly body taken with a sextant at the Greenwich Time given by the chronometer corrected for its error and rate, the position of the ship is determined.

The method at present in use was introduced at the Royal Observatory in 1916 and is intended to eliminate errors of personality. A contrivance is attached to the eye-piece called the impersonal or the travelling-wire micrometer. A single vertical wire can be made to move across the field in the focal plane of the object-glass by the turning of a large button or screw head. The observer's business is to follow the star across the field by turning the screw head, keeping the star's image always bisected by the wire (*see* figure, page 709). The apparatus itself, by making electric contacts, automatically records the progress of the wire on the chronograph's drum. Personal errors are thereby reduced to about one-tenth of their value with the method previously in use, different observers differing by perhaps one-hundredth of a second.

The accuracy with which the time can now be determined by observation of one star is of about 0·05 second. Every day that the sky permits, observations are taken of perhaps ten stars by day or by night, and the time deduced from the whole series is of a greater accuracy than that from one, reaching about one-fiftieth of a second. The daily routine includes observations for testing the telescope for errors of azimuth, of level, and of collimation, for though it is mounted on heavy piers with great refinement, including the counterpoising of the greater part of the weight of the instrument



[L. E. A.

THE TRANSIT CIRCLE, ROYAL OBSERVATORY, GREENWICH.

The instrument used for determining the time by the transit of stars across the meridian. The observer is seen following the image of a star across the field of view and keeping it bisected by the travelling vertical wire by turning the stud of the micrometer. The latter automatically records electrically on the chronograph. C P is the finely graduated circle for determining the declination of the star at the same observation.

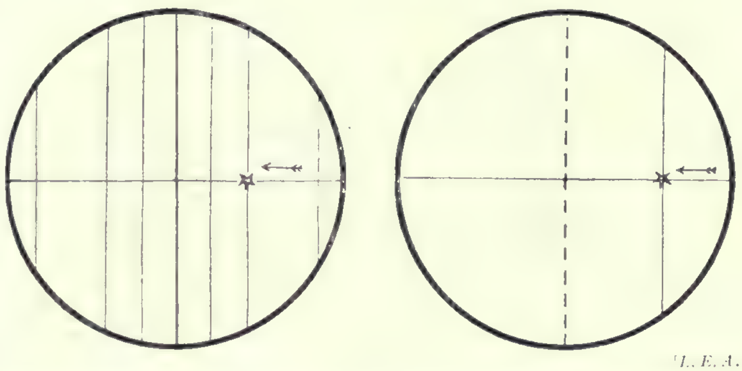
to relieve the bearings of strain, there is movement from day to day and from season to season from the continual shifting of the subsoil on which the piers rest. Corrections for the errors found daily have to be made to the observations. No scientific man expects his instruments to record with perfect accuracy, for nothing is perfect. His aim is rather to know with as much accuracy as possible the errors of his instruments and to be able to apply the proper correction, and then to know within what limit he can depend on the results. The standard sidereal clock at Greenwich does not read the true sidereal time ; it is always in error, but this is of no consequence. The purpose of the time department of the observatory is to know two things about this clock, (1) its error, and (2) its rate. Correction can then be applied to obtain the true time at any moment. This standard sidereal clock is the one designed by the Astronomer Royal, Airy, about 1870. It has the detached escapement (similar to that of a chronometer) applied to a pendulum.

The standard time of the observatory is the time derived from this sidereal clock, but this is of little use in civil life for which mean solar time is needed, and it is part of the work of the Observatory to distribute this mean time. For this purpose another clock is provided—the mean time clock. This is subordinate to the sidereal clock and is rated and adjusted from it. It has the Graham dead-beat escapement. Owing to the fact that this clock is required to signal automatically the Greenwich Mean Time over the telegraph wires to all parts of the country, it has to be put to the correct time every day. The amounts by which it has to be corrected each day are so small—only fractions of a second—that special means have to be used. The pendulum carries a permanent magnet that passes with its swings over the poles of a solenoid, that is, a coil of wire without core. Every morning before ten o'clock the reading of the clock is compared with the true G.M.T. (Greenwich Mean Time) as obtained by conversion from the sidereal time. The error of the clock is then corrected by passing

a known current through the solenoid for such a length of time as will, as judged by past experience, cause the pendulum to gain or to lose the amount by which it is in error. The clock is then ready to send its ten o'clock signal automatically over the telegraph wire. At the correct instant the signal is sent to the General Post Office and from there the Postmaster-General is responsible for distributing it to the principal post offices in the country over the ordinary telegraph wires. Just before ten these wires are held clear of other business and switched on to the time signal circuit. At one o'clock also the mean time clock is corrected by the same process. It sends out its signal at every other hour of day and night, but as special corrections are only applied before ten and one the time given at other hours is not so dependable for accuracy, as the clock will have accumulated some degree of error.

A duplicate mean time clock has lately been set up. In case the electric contacts fail at any time —and they have done so in the past—it is only necessary to switch on to the duplicate. All these clocks, together with some others of interest for comparison, are housed in a little room with double doors, the temperature in which is kept approximately constant by means of an electric thermostat arrangement.

When communication was slow between different parts of a country each town was accustomed to use its own local time. As railway travelling became more general this confusion of local times was found to be inconvenient. Greenwich time had long been used by seamen, as it was here that their chronometers were corrected and rated, but it was not until 1880 that the law was passed making Greenwich Mean Time the legal time of Great Britain. In other countries also the time of the capital town or of the chief observatory came to be generally adopted as the legal time of those countries. In the meantime British ships were carrying Greenwich time all over the world and it became convenient for ships' charts and maps generally to be based, as regards the longitude shown, on the Greenwich meridian. When the United States of America came to consider the fixing of a standard time for the whole Confederation, it was obviously impossible to adopt the same time across the whole continent, differing as it does in the extreme east and west by as much as four hours of local time. They therefore in 1883 initiated the zone system based on the Greenwich meridian. The zones, so-called, are strips of country running north and south fifteen degrees of longitude in width. In any two adjacent zones the standard time differs by one hour exactly, but all over the country the minutes shown by the clock are the same as at Greenwich. From this beginning the zone system has gradually spread all over the Earth so that now with few exceptions the standard time at all places is Greenwich Mean Time, differing only by whole hours, or in exceptional cases by an odd number of half hours. The limits of the zones do not always follow rigidly the lines of longitude, but are bent for convenience in many places to follow coast lines and the frontiers of States. The only countries of importance that have not adopted this zone system based on the Greenwich meridian are Holland, Russia, Argentina and Mexico. Thus gradually by a natural evolution the Greenwich meridian has become the basis of all time and all longitude.



SPIDER-THREADS IN THE FIELD OF THE TRANSIT INSTRUMENT.
With the older methods of observation of transits the threads were arranged as on the left. As the star crossed the field towards the left, the observer estimated the interval between two ticks of the clock when the star was bisected by each wire in turn ("eye and ear" method); or he pressed an electric button recording on the chronograph at each bisection (galvanic method). The field of the impersonal micrometer is shown on the right. The vertical wire is made to travel with the star by the turning of a stud, and the instrument itself records on the chronograph.

[*L. E. A.*

ROYAL OBSERVATORY, GREENWICH.

View of the Observatory from the east. Flamsteed House, built by Wren, is in the middle of the picture, with the Time Ball, since erected on the N.E. tower, and recording meteorological instruments on the roof. The Greenwich Meridian is determined by the site of the transit circle in the lower building on the left of the picture.

The line of longitude at 180° east and west of Greenwich is called the Date Line. To the west of this line the date — the day of the week and the day of the month — is one day in advance of that to the east of the line. The date changes abruptly across the line, though the hour of day maintains its continuity. To a world that uses the same calendar everywhere, the existence of such a line is inevitable. By a fortunate hazard the prime meridian of Greenwich is so situated that this date line on the opposite side of the Earth passes for nearly its whole length across the Pacific Ocean. In the north it is somewhat diverted so as to pass through the Behring Straits and thereby avoids cutting across the extreme north-east of Asia ; and it threads its way somewhat irregularly among the oceanic islands of the Pacific. A ship travelling eastward across the line will pass through one day of the calendar twice, whereas one sailing westward will require to omit one day. Paradoxical events are liable to occur in the neighbourhood of the Date Line. A child born at noon on the 1 January, 1924, may have a twin younger brother born at 12.15 p.m. on the 31 December, 1923, if in the meantime his mother has crossed the line from the west. Or again, a man may have been killed by an accident on the 30 June, whereas he was proved to have left one of the Pacific Islands on the 1 July of the same year in a boat for another island farther east. It is as well that such a line should not traverse an inhabited country.

For the last hundred years the testing of chronometers for the Navy has been included in the work of the Royal Observatory. In the chronometer room is to be heard the buzzing of innumerable chronometers in process of having their rates tested under varying conditions of temperature. Besides ovens for testing them under tropical conditions, a freezing chamber similar to that used on board ship for the preservation of meat is used to test for voyages in high latitudes.

Since 1833 a time-ball on one of the north towers of the Observatory has been dropped every day at one o'clock for the use of the shipping in the river below. A time-ball is also released at Deal by the one o'clock time-signal, and clocks at Portsmouth, Portland and Devonport are controlled by the ten o'clock signal and these clocks release time-balls for the use of the naval establishments. The Westminster clock is rated from the Observatory. An automatic signal is sent daily by the clock to the Observatory by which its error is observed. It is of interest to know that this clock generally shows an error of less than one second and that one of three or more is very rare.

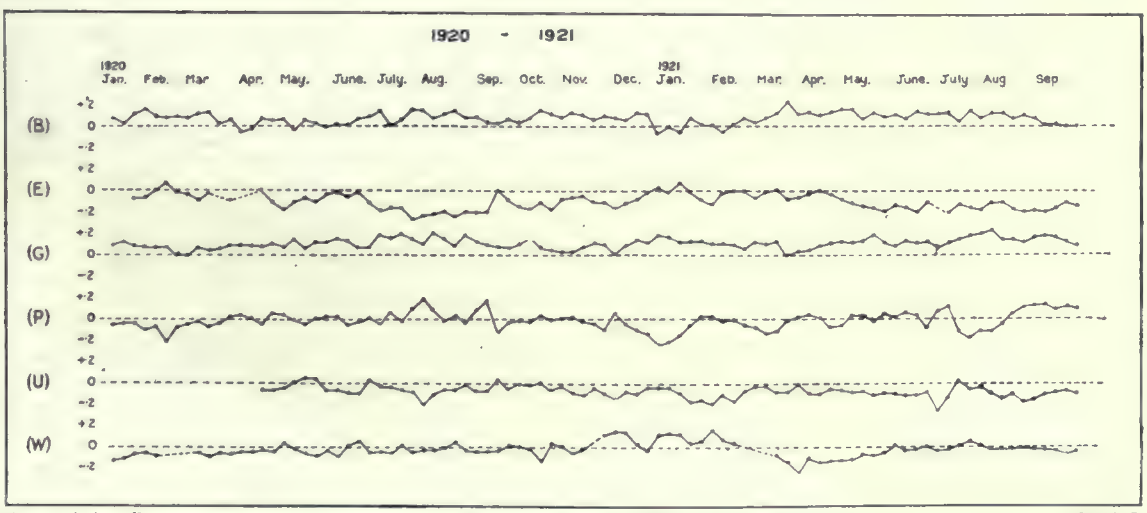
A few words must be devoted to the subject of wireless time-signals, now becoming of such great importance for the distribution of correct time. These were instituted primarily for the assistance of navigation, to enable seamen to learn the errors of their chronometers. In this connection it is curious to remark that no such time-signal has yet been instituted from Great Britain, considering that such a large proportion of all shipping is owned and run by the British. We make use of the

signals of other countries, those from the Eiffel Tower, Paris, and from Bordeaux ; from Nauen, near Berlin ; from Moscow, from Japan, from Annapolis, near Washington ; from Honolulu in the Sandwich Islands, and from other places. These all give the Greenwich hour at different times of the day. Several of these are picked up daily at the Royal Observatory and compared with Greenwich standard time by automatic registration with a syphon recorder.

An invitation was given some years ago by the French authorities to the Astronomer Royal and to the principal observatories of Europe to receive the Eiffel Tower time-signals, to compare them with their own time as observed, and to report the result of this comparison each day to Paris by post card. The purpose of this invitation was that all the observatories should thus collaborate with a view to deducing from the many authorities a more accurate time than could be obtained from one observatory alone. Such a method of collaboration would be of special value when any one observatory had been prevented by clouds from taking transits for a day or more. No great result has as yet come from this scheme.

It is a convenient feature of wireless time-signals that in general no correction is necessary for the time the signals take to travel. These electro-magnetic waves travel with the velocity of light, 186,000 miles a second. When a few years ago the longitude of Adelaide Observatory, Australia, was being determined, comparison with local time was made both at Adelaide and at Greenwich of rhythmic signals from Lyons, in France. The allowance made for the time of passage of the signal to Adelaide was 0·04 second. The time taken then between Paris, Berlin, or Moscow, can be neglected. An allowance of 0·02 second is made at Greenwich when making comparison with Washington.

Time signals are regularly picked up and recorded by observatories, and the times of the various authorities can be compared. Dr. R. A. Sampson, Astronomer Royal for Scotland, has lately collected some comparison figures and published the results. He dealt with the times as determined by Greenwich, Berlin, Paris, Edinburgh, Washington, and Uccle in Belgium. Taking the mean of the six and then finding the differences of each in turn from this mean, he arrived at the results which are plotted on the chart below. A study of this chart, bearing in mind that the dots represent the means of seven days, will enable one to judge with what degree of accuracy time is determined at the several observatories. The discrepancies shown between the different determinations and the



By permission of] [*R. A. S.*

TIME AS DETERMINED AT SIX OBSERVATORIES.

The time determinations of the six observatories were compared by daily wireless time signals. Dr. R. A. Sampson took the mean of the six determinations as a basis and then found the difference between each and this basis and plotted them in weekly averages on the above curves. The scale on the left is in tenths of seconds. B, Berlin; E, Edinburgh; G, Greenwich; P, Paris; U, Uccle (Belgium); W. Washington.

mean, and between one another, are larger than would have been expected, the former reaching 0·2 sec. on several occasions and the latter 0·3 and more. They take the form of (1) pronounced oscillation, and of (2) continuous drifts. Dr. Sampson in his discussion of the matter in his search for their origin, considers to what extent lateral refraction by the atmosphere can account for them and concludes that whether or not this may explain the oscillation it cannot account for the drifts. The former may be due to instrumental errors but the latter remains at present unexplained.

CHAPTER XX.

THE AMATEUR AT WORK.

By Instructor Captain M. A. Ainslie, R.N., B.A., F.R.A.S., F.R.M.S.

THE Amateur who takes up practical observing, as distinct from the study of theory, may do so with one of two objects in view: either he may regard his hobby as a means of obtaining an interesting form of relaxation from everyday cares and distractions, in which case he will find even the most modest "star-gazing" wonderfully and delightfully effective in, so to speak, "taking him out of himself," and, for the time being at any rate, giving him a calm and refreshing freedom from worries and petty troubles; or he may take up this truly fascinating pursuit with the view of doing some really useful work and of advancing knowledge, even in a small degree. If he takes it up with the former object in view, he is to be congratulated and encouraged by all possible means, for he will very likely, sooner or later, join the class of serious workers, and in any case will gain nothing but benefit and enjoyment from the contemplation of the wonderful works of the Creator; while to him who embarks on serious work, however humble in its scope, the work itself, which will grow more and more engrossing as times goes on, will form the best possible encouragement and incentive. It is for the would-be serious worker that this chapter is primarily intended.

Photo by *Dr. W. H. Steavenson.*

THE PLEIADES.

This well-known group, as seen by most unaided eyes, only consists of six or seven stars. The immense advantage of even a small telescope on such an object is well shown in this photograph, which represents its appearance in a "finder" of magnifying power about eight diameters, or a prism binocular of about the same power.

Many would-be workers in the vast field of Astronomy are, without doubt, deterred by an idea that at the present day the great observatories, with their giant telescopes and their highly skilled and trained staffs—as well as, in many cases, their apparent command of boundless wealth for the provision of new instruments—have left little for the Amateur to do; and it is perhaps true that at the

present time certain branches of observation—for example, star-charting by photography, determination of stellar parallaxes, precision work on position of stars and planets, and the elaborate statistical work required for the testing of the theories of stellar distribution advanced by the great intellects of the day—are best left to the great observatories and the professional workers generally, who are able to cope with such work. But there are many branches of observation to which the professional does not apply himself to a great extent, and which are eminently suited to the amateur. To take, perhaps, the most conspicuous case, a very great proportion (perhaps nearly the whole) of our knowledge of the physical conditions of the Moon and Planets is due to the work of amateurs, and the same may be said of Variable Stars; practically all that we know about Meteors is the result of patient nightly watches by amateur enthusiasts; even in the difficult field of double-star observing, in which one would expect the giant telescopes to have appropriated the whole of the work, amateur observers are constantly sending in results of the highest precision and value. And it may also be said that the professional astronomer, to whom a star is very often only of interest when it has printed its image on a photographic plate, and who really hardly finds himself under the necessity of *looking* at the stars at all, is far less likely than the amateur to attain to a comprehensive acquaintance with the star-groups and constellations, and, one might add, is apt to miss much of the pleasure derived by the amateur from their contemplation.

Photo by] [*Dr. W. H. Steavenson.*

THE DOUBLE CLUSTER IN PERSEUS.

The beautiful double cluster in Perseus is a splendid object in small telescopes. It is here shown as it would be seen in a three-inch refractor with a magnifying power of about twenty-five diameters.

From] [*"Knowledge."*

THE REV. T. W. WEBB.

The late Rev. T. W. Webb (1807–1885) was a "father to all amateur astronomers." His extremely valuable work, "Celestial Objects for Common Telescopes," first published in 1859, has passed through several editions, the last—the Sixth—edited by the Rev. T. E. Espin, having appeared in 1917. It is still a *vade mecum* for the amateur, who should certainly include it in his astronomical library.

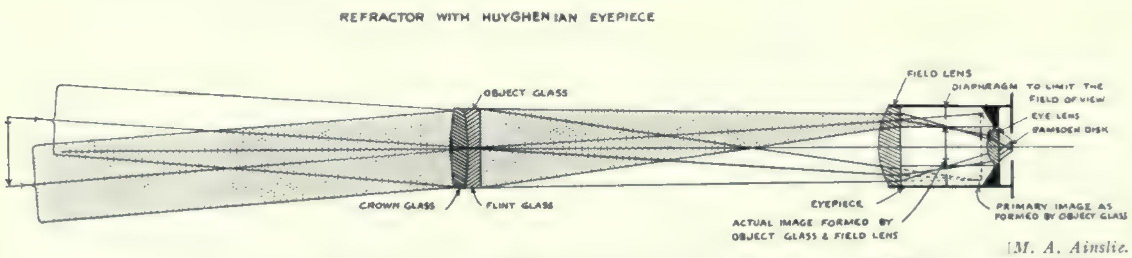
This being so, let us proceed to the consideration of the amateur's equipment for his work. Those who are endowed with a deep purse, unlimited leisure time, and abundance of space for the erection of complete observatories and powerful instruments, may possibly find little in the ensuing pages that will be of much use to them; their object is rather to show the amateur of modest means and opportunities how best he may arm himself for the fray, and to indicate what he really must have, as distinct from what may be considered as luxuries.

To start with, he must have a telescope. And even this may be disputed, for a surprising amount may be done without optical aid: the study of Auroræ and of the Zodiacal Light, of Variable Stars down to about the fourth magnitude, of Novæ soon after their appearance, of the details of Comets (if sufficiently bright), of the visibility of stars under varying conditions of atmosphere, twilight, and so on, and during Solar or Lunar Eclipses, are some of the ways in which the unaided eye may be usefully employed. And, as Webb ("Celestial Objects for Common Telescopes," 6th ed., vol. I, p. 2) said many years ago, "even diminutive glasses, if good, are not to be despised; they will show *something* never seen without them."

How true Webb's remarks are may be realised by any possessor of a good pair of binoculars, whether " prism " or of the older form, if he will direct them to the Moon or Jupiter or brilliant constellations, such as Cygnus and Orion, or to groups like the Pleiades, Berenice's Hair, and many others, when he will be astonished at the immense gain in brilliancy and detail over what can be seen with the eye only. When it is realised that with a good prism binocular (power six), many of the Lunar craters are to be seen ; Jupiter shows a perceptible disc, and the satellites are clearly seen ; and that it is just possible, if the glasses are kept quite steady, to recognise the existence of Saturn's ring, no more need be said to assure the reader that these small telescopes will at any rate do *something*. On Comets, Variable Stars, and the larger nebulæ and clusters, *e.g.*, those in Andromeda, Orion, and Perseus, these little glasses are really remarkably effective.

But such glimpses whet the appetite for more, and the original statement still holds good—the amateur must have a telescope. We will now consider what sort of telescope he should obtain, and how it should be used.

Telescopes, as the reader probably knows, fall into two main classes—refractors and reflectors. In the former, the image that is to be examined by the eyepiece is formed by a lens, composed of two or more pieces of glass, called the object-glass, or objective. In the reflector, the same function is performed by a large mirror, slightly concave on its front surface, and having an extremely thin film of pure silver deposited on this front surface and highly polished.



[M. A. Ainslie.

ACTION OF REFRACTING TELESCOPE WITH HUYGHENIAN EYEPIECE.

Here the paths of the rays of light from the extreme points of the object are shown, and it will be noticed that the field lens collects rays that would otherwise pass clear of the eyelens, and bends them inwards towards the axis. At the same time the introduction of the field lens somewhat reduces the magnifying power, as will be seen from the figure. This, however, is of no moment, as the eyelens can be made of somewhat shorter focal length to compensate.

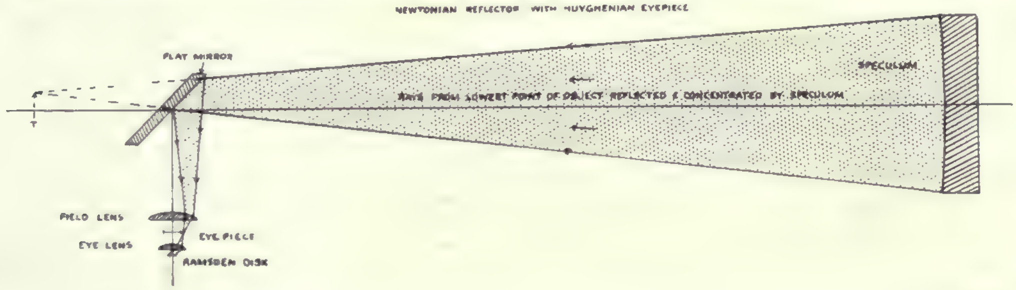
Much has been said and written as to the relative merits and advantages of the two forms of telescope, and complete agreement on these points will probably never be reached, each class having its votaries and each class its detractors, but the matter may perhaps be summed up impartially as follows :

For occasional use, by those who do not wish to take up any branch of regular observation, and for the inspection of the brighter objects—such as Sun and Moon—without special attention to minute detail, a small refractor has undeniable advantages. If its aperture is not less than three inches, and still better if it is four inches, it will afford wonderfully beautiful views of Solar and Lunar features, of the brighter clusters and nebulæ, and of the main features of the brighter planets. Such an instrument is always ready for use, and can be made portable, so that on a fine night it can quickly be carried out of doors and as quickly stowed away when done with. Its grasp of light, however, will not be sufficient to deal properly with fine details or faint objects, although with a first-class lens—and no other sort is worth having—much more may be seen after a little experience than might at first be thought possible. Much useful work has been done, for example, on the planet Jupiter with instruments of three to four inches aperture, and with these small sizes the ever-present atmospheric disturbance, which is such an obstacle to the performance of larger telescopes, is of comparatively little moment. The images of stars given by a refractor are generally better than those afforded by a reflector, and in the larger sizes very much better. On the other hand, although the refractors

of the present day are styled "achromatic," it is impossible, except by special and very expensive methods of construction, to render them perfectly free from the exhibition of a certain amount of false colour, which is liable to render any estimates of colour (*e.g.*, of stars and planetary markings) of very doubtful value. A refractor, however, if well made and carefully adjusted, will remain in adjustment ; and the efficiency of the instrument is not so liable to suffer from inexperience or neglect as is the case with the reflector.

On the other hand, the reflector, although in comparison with the refractor unwieldy and sometimes troublesome, has very great advantages of its own. It is very much less costly than a refractor of the same power ; the mirror is of one piece of glass only, which need not be the very expensive optical glass necessary for an object-glass, and which only requires one surface to be worked. In fact, a refractor is perhaps six or seven times as costly as a reflector of the same capacity.

Thus, if it is desired to obtain the most effective telescope possible for a given outlay, the reflector must of necessity be adopted ; and for the amateur who desires an instrument with which he will be able to make observations of the finer details of the Moon and Planets, there is no doubt that from this point of view the reflector is greatly to be preferred. It is sometimes said that the reflector "breaks down on the Sun," but this is very far from being the case, and, if used intelligently, it will afford exquisite views of solar detail in no way inferior to those given by a refractor of similar aperture.



[*M. A. Ainslie.*

ACTION OF NEWTONIAN REFLECTOR WITH HUYGHENIAN EYEPIECE.

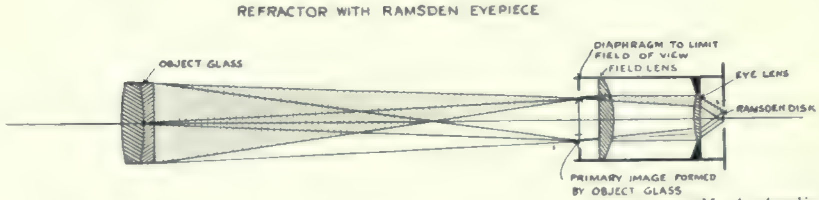
The small flat mirror in the Newtonian reflector sends the light from the large speculum out to the side of the tube before it comes to a focus. Only the rays from the lowest point of the object are here shown, and it will be seen that the flat has to be of sufficient size to include these rays. In the figure the size of the flat mirror and eyepiece are considerably exaggerated for clearness.

The great advantage of a reflector, however, as far as concerns the images it affords, is that it is perfectly achromatic ; the coloured fringes seen round bright objects in the refractor are conspicuous by their absence, and in all observations of the colours of planetary markings and of stars, the reflector is beyond question the final court of appeal.

An advantage of the reflector which is by no means to be overlooked is its much greater compactness. A refractor, unless a specially short focal length is demanded—in which case the difficulties of construction, and consequent expense, are greatly increased—is rarely less in focal length than fourteen or fifteen times its aperture ; a reflector can be made of first-rate quality with a focal length not exceeding seven times the aperture of the mirror. It is possible, for example, to turn out a good mirror of nine inches aperture and little over five feet focal length ; a refractor of the same aperture would require a focal length of something like eleven feet. It is perfectly possible to carry indoors and out-of-doors a reflector of nine inches aperture, in a wooden tube, and to place it on its stand and remove it therefrom without the least difficulty ; a refractor of the same aperture would, of necessity, be a fixture on its stand, and would require a somewhat costly observatory for its shelter.

Another great advantage of the reflector—at least of the Newtonian form, which is almost universally adopted—is that the eyepiece is much more conveniently situated, and that it is possible to arrange for the view to be horizontal or even downwards. The advantage of this from the point of view of comfort, as compared with the strained and uncomfortable attitudes necessary in order to observe with a refractor an object of any great altitude, is very real. From experience with both

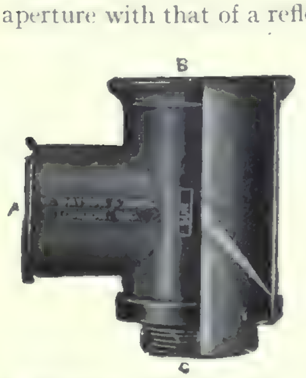
forms of telescope, the writer would say that an hour's observation with a reflector is less tiring than twenty minutes with a refractor. Of course, it is true that large refractors, such as are to be found in fixed observatories, are usually provided with special observing chairs, on which the observer may recline at ease with his head supported in a convenient position at the eyepiece, but this adds considerably to the cost of the whole outfit, and for the ordinary amateur it must be looked on as a luxury. On the other hand, a reflector of as much as twelve or thirteen inches aperture can be conveniently worked with a simple step-ladder to stand on or a large box to sit on, and the slow motions necessary for following an object can be arranged so as to be manipulated with the utmost comfort.



M. A. Ainslie

ACTION OF REFRACTING TELESCOPE WITH RAMSDEN EYEPIECE.
In the Ramsden eyepiece the field lens is placed beyond the focus of the object glass, and its flat side turned away from the eye. The result is a flatter field of view: objects at the edge of the field appear sharper than with the Huyghenian eyepiece.

It must be admitted, however, that the views of celestial objects obtained with a reflector are apt at times to be somewhat disappointing. It often happens that on a brilliant night, when one would think that perfect views might be had, the image is boiling and unsteady owing to atmospheric disturbance—the crossing and recrossing, in the line of sight, of innumerable currents of unequally heated air. On any given night the refractor is far less liable to failure from such a cause. This is chiefly because the beam of light from the object-glass of a refractor passes only once through the tube; and the tube is closed at both ends, so that the air within it does not partake of the motion of the air outside. In the reflector the tube is perforce open at its upper end, and the light has to pass along it twice before arriving at the eyepiece. Hence a refractor of, say, eight inches aperture will on most nights give perceptibly better images—especially of stars—than a reflector of the same aperture; and as it may be estimated that a reflector of about nine and a half inches aperture would be required, as a rule, to give the same light-grasp as a refractor of eight inches, the reflector is in this respect at a still further disadvantage, since the effect of atmospheric disturbance increases very rapidly with increasing aperture. It would not be fair, of course—although this is frequently done by those who disparage the reflector—to compare the performance of a small refractor of about three to four inches aperture with that of a reflector of eight or ten inches. Many nights occur on which the images would be perfectly steady in the former and quite unsteady in the latter; but no one would claim that the small refractor was a more effective all-round instrument.



By courtesy of Messrs. W. Watson & Sons.

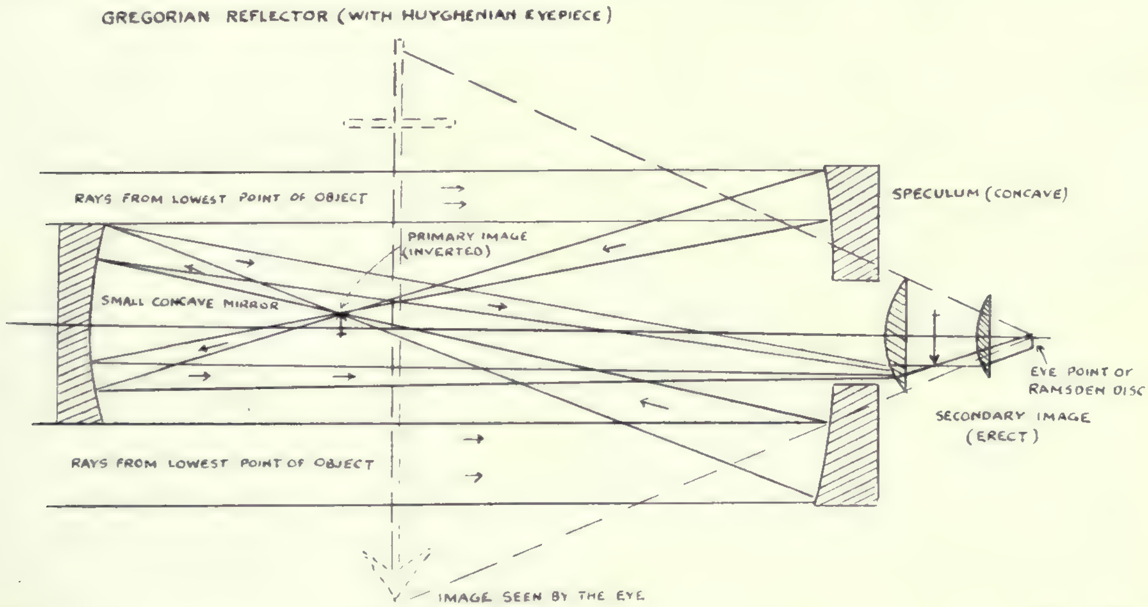
THE SOLAR DIAGONAL REFLECTOR.
A plane surface of unsilvered glass at an angle of forty-five degrees with the axis of the tube, reflecting a small fraction only of the Sun's light and heat to the eyepiece.

It has been said above that one of the advantages of the refractor is that it is always ready for use. The same cannot, unfortunately, be said of the reflector, for there is no doubt that the film of silver which forms the actual reflecting surface is not by any means of a permanent nature, though it will generally last, with care, for several months, or even for two or three years. At the same time, its renewal is not a difficult matter, nor—especially if the observer does it for himself—a very expensive one. There are several good formulae published for the purpose, and no great skill is required to perform what is, in any case, a very pretty chemical experiment.

The mirrors, or "Specula," as they are generally called, of reflecting telescopes cannot be held in their mounts, or "cells," as firmly as the object-glasses of refractors, as the least strain on the mirror, especially in the larger sizes, produces a microscopic amount of bending, which is quite sufficient to destroy its performance. Hence, one sometimes hears it

stated, usually by those who have no great experience of reflectors, that a reflector is constantly getting out of proper adjustment. This is, however, hardly the case, at any rate if the cell of the mirror is properly designed. The writer has known an 8½-inch reflector remain in perfect adjustment for more than two years at a time, and even when the mirror, after that period, was taken out of the cell for re-silvering, it went back into very nearly correct adjustment when replaced, and only required a touch of the adjusting screws to put it right. The very common statement that specula require constant attention to keep them in adjustment is, to say the least, an exaggeration. At the same time, they do occasionally require attention, and later in this chapter will be found some directions for their adjustment.

As regards light-grasp, which governs the ability of the telescope to show faint stars or satellites, reflectors are somewhat inferior to refractors, especially if the silver film is not very fresh. The light grasp of a 6½-inch reflector is certainly as great as that of a 5-inch refractor, even when the silver is not very fresh ; probably a freshly silvered 6½-inch mirror would be equal to a 5½-inch refractor in this



[*M. A. Ainslie.*

ACTION OF THE GREGORIAN REFLECTOR.

A form of reflecting telescope which was much in favour during the Eighteenth Century, prior to the invention of the achromatic telescope. The primary image is formed by the speculum, and an enlarged secondary image of the primary is formed by the small concave mirror, the light passing to the eyepiece through a hole in the speculum. The image is erect, as in an ordinary terrestrial telescope, but this is of no advantage for astronomical work. This form of reflector has the disadvantage that with low powers the field of view is very small. The size of the small mirror is here greatly exaggerated for clearness.

respect, or possibly rather superior. The chief causes of loss of light in a refractor are by reflection from the four surfaces in the object-glass, and by absorption in the glass itself. In the reflector light is lost by imperfect reflection at the two silver surfaces of the large speculum and of the small flat mirror which reflects the light out to the side of the tube. Of these causes, the loss in the refractor by reflection at the surfaces of the object-glass is practically constant at about 15 per cent. The loss by absorption in the material of the object-glass is, in the case of small sizes, almost negligible.

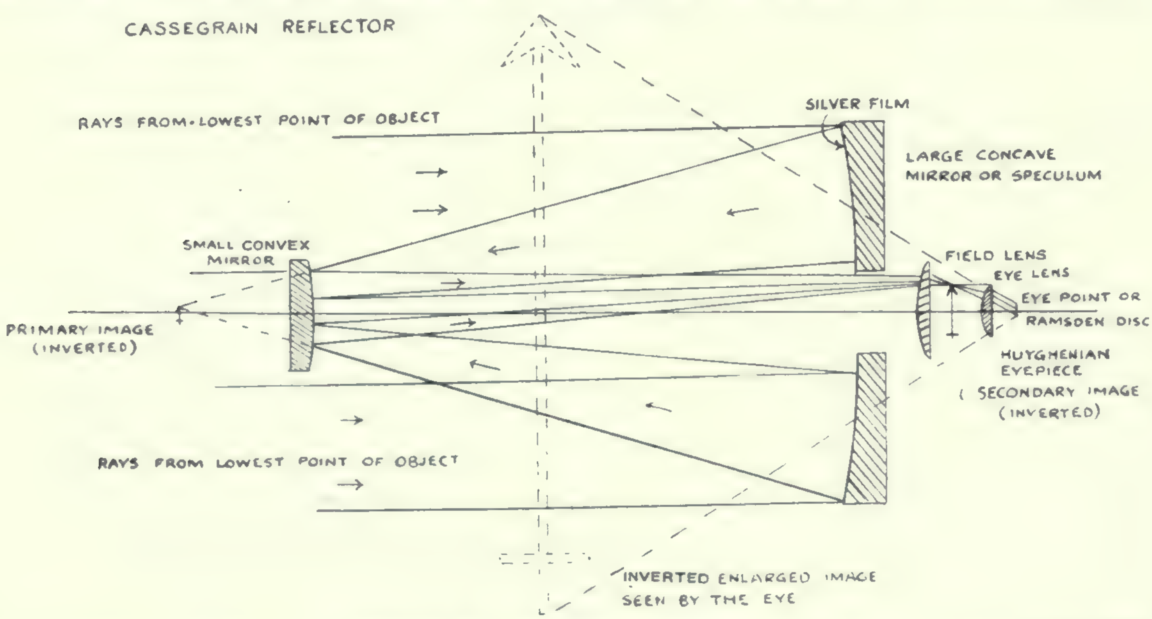
When we come to very large apertures, however, the reflector more than holds its own in light-grasp, on account of the great absorption of light in the object-glass of the refractor and it is probable that the light of an 18-inch refractor is actually less than that of an average 18-inch reflector ; and in still larger sizes the difference is even more marked.

All said and done, the amateur who takes up regular and serious observation in some definite branch of Astronomy will probably do well to obtain a reflector of about 8½ inches aperture. Such

an instrument, if of first-rate quality, will possess sufficient grasp of light and defining power to render visible much of the finer detail on Moon and Planets; indeed, it may be said that most of our present knowledge of these bodies is the result of patient and long-continued systematic observation with such apertures, and in the observation of these bodies the reflector seems to have done, on the whole, quite as well as the far more costly refractor. Even a 6½-inch reflector will do well on planets, as is shown by the work of Mr. A. Stanley Williams, whose admirable observations of Jupiter, extending over many years, were done entirely with this aperture. If the amateur is prepared to face the slight extra difficulty in use due to the increased size, he may employ a 12-inch, but he must be prepared to encounter somewhat greater trouble from atmospheric disturbance, although on a good night there is a distinct advantage to be gained with increase of aperture.

Those who contemplate taking up observation merely as an occasional recreation, will be well advised to limit themselves to a refractor of not less than three inches aperture, while three and a half or four inches would be distinctly better. Such an instrument is handy and may be made easily portable, while it is capable of affording excellent views of the heavenly bodies, even if it does not possess the necessary light-grasp for faint objects. On the Sun and Moon a small refractor is very effective; while to those who are suitably situated, its capacity on terrestrial objects is worth consideration.

Let us now turn to the various objects which the amateur will wish to observe, and—to place the most conspicuous object first—let us commence with the Sun. First of all a warning is necessary. The light and heat of the Sun are so great that it is never safe to attempt observation without proper safety appliances; many an amateur has permanently injured his eyesight by insufficient precautions. A simple dark glass cap over the eyepiece is not sufficient: with any aperture greater than about two inches it will—especially if red in colour—be cracked by the intense heat concentrated by the object-glass, and with any aperture exceeding four or five inches, it may even be melted. The appliance known as the "Solar Diagonal" should always be adopted. This consists of a plane surface of un-

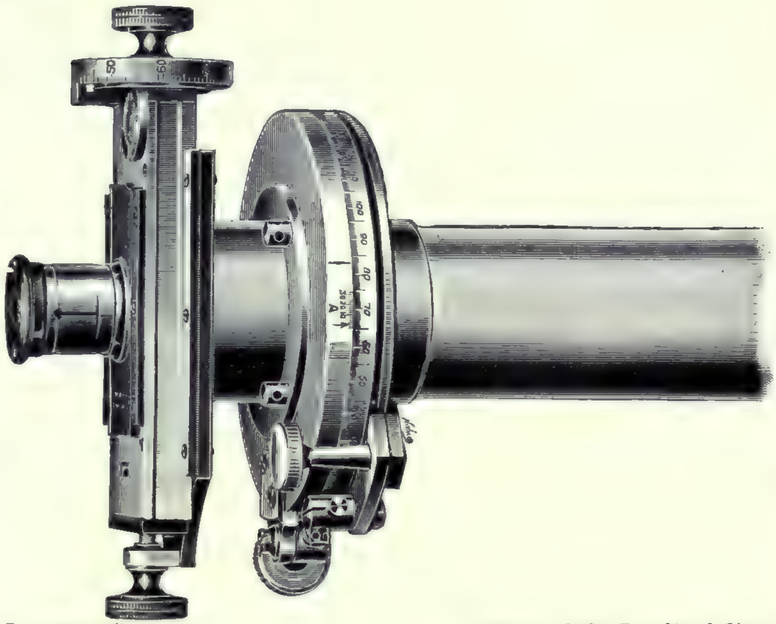


[*M. A. Ainslie.*

ACTION OF THE CASSEGRAIN REFLECTOR.

In this form of reflector the rays from the speculum, which would form the primary inverted image at its focus, are intercepted by a small convex mirror and returned through a hole in the speculum to the eyepiece, where they form an enlarged secondary image, still inverted. For many years this form of reflector was considered inferior to the Gregorian, but the principle is now much employed in the giant reflectors in America and elsewhere. Its great advantage is that the effective focal length can be made almost indefinitely great, while this telescope is the shortest and most compact of any. For low powers, however, the field of view is rather small.

silvered glass, mounted at an angle of 45°, so as to reflect the light out at right angles to the axis to the eyepiece ; to avoid double images the reflecting surface is usually one side of a prism of small angle, the other side of which reflects the light falling on it well clear of the eyepiece. Such an appliance reduces the light and heat to about one-sixteenth of their incident value, and even this will be too much for the eye ; a dark glass cap must still be employed, except in very misty or foggy weather. It is well to have several dark glasses of different depth to allow for varying conditions, and these are much better if made of some neutral tint, red being wholly unsuitable, though green and blue are not bad. Owing to the unsteady state of the air, almost always present when the Sun is shining brightly, a power of 90 or 100 is about the highest that can be used under ordinary conditions, though occasionally this may be much exceeded ; but it is very rare that anything over 200 is of much service. Other appliances, such as the " Polarising Eyepiece," which depends for its action on the polarisation of light by two reflections, have been devised, and are somewhat costly ; for ordinary purposes the " diagonal " above-mentioned is probably the best safeguard. I will do no more than allude here to the possibility of observing, with a suitable spectroscope fitted to even a small refractor, the solar " prominences." This will be found fully discussed elsewhere.



By courtesy of] [*Messrs. Cooke, Troughton & Simms.*

THE PARALLEL WIRE MICROMETER.

The principle of this micrometer has already been explained on page 517. This illustration shows the frame carrying the wires, with the screws for moving them, and the circle for measuring " angle of position."

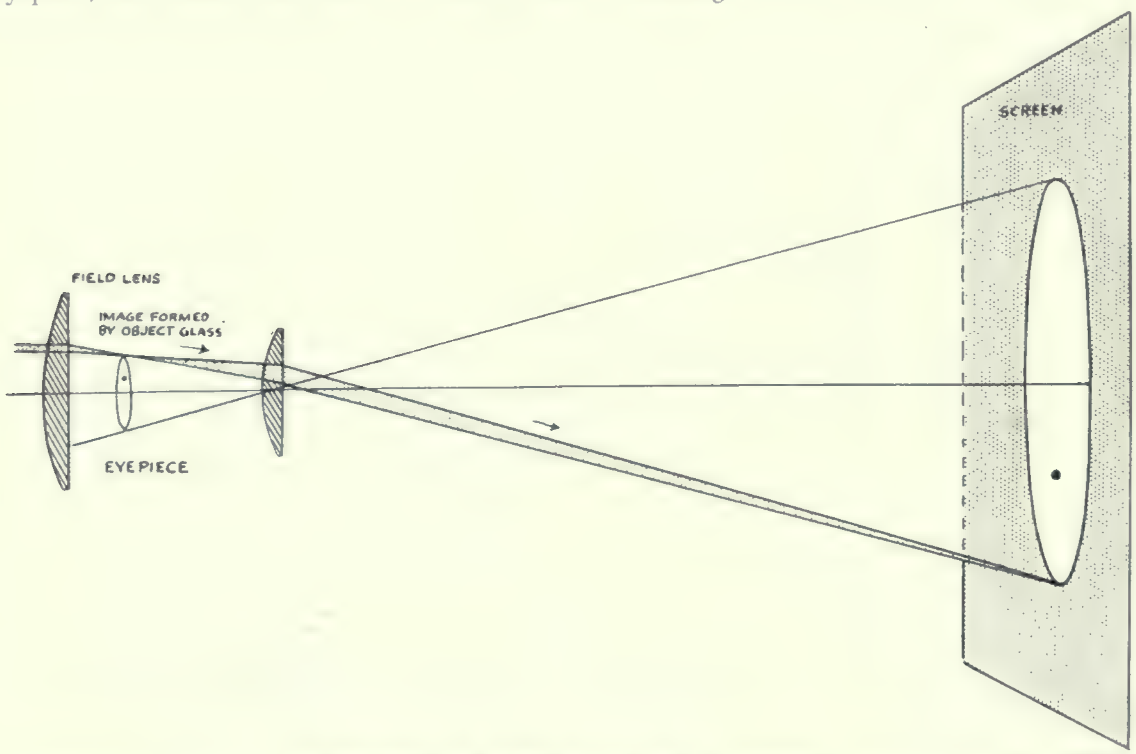
When the "Solar Diagonal" is used for drawings of the details of sun-spots, it should be borne in mind that since there is only *one* reflection of the light, the image seen by the eye will be reversed " right-and-left " (or " up-and-down ") as in a looking-glass. To show the details in their correct relative positions there must be an *even* number of reflections.

Under ordinary conditions, the air is too tremulous to allow of the useful employment, on the Sun, of an aperture of more than about 5 inches ; and those who wish to use an 8½-inch reflector on the Sun will, as a rule, find it advisable to reduce the aperture by a stop, which may be cut out of black card or zinc, and fitted either over the end of the tube or over the speculum. If over the end of the tube—which is probably the best place for the stop, as to a certain extent lessening the disturbance of the air in the tube—it is as well to have the outer surface of the stop painted white : this will reflect a considerable amount of the Sun's heat, and tend further to steady images. Whether a reflector or refractor is used, some form of shade attached to the telescope will be found a great advantage, especially in summer ; and the larger it is the better, although in a high wind it is liable to cause some vibration of the instrument. A light canvas screen on a wire frame, arranged to fit round the upper end of the tube, has proved very useful and conducive to the observer's comfort. This will obscure the view from the finder, but the Sun is so easily brought into the field of view that this is of no moment.

Although 5 inches or so is, as a rule, the largest useful aperture on the Sun, it occasionally happens

that much larger apertures may be of advantage ; on a certain morning in May, the writer was able to use the full aperture of a nine-inch reflector, the air being quite still and very misty. With this large aperture the delicate stippling of the Sun's surface was beautifully defined with powers even up to 500 diameters, and the minute details of the spots were wonderfully distinct. This, however, must be regarded as altogether exceptional, although a still, misty morning, so long as the Sun's altitude is not less than about 20°, affords perhaps the best conditions for solar observation. On such a morning the atmosphere has not had time to become unevenly heated, and the troublesome air-currents are at their minimum.

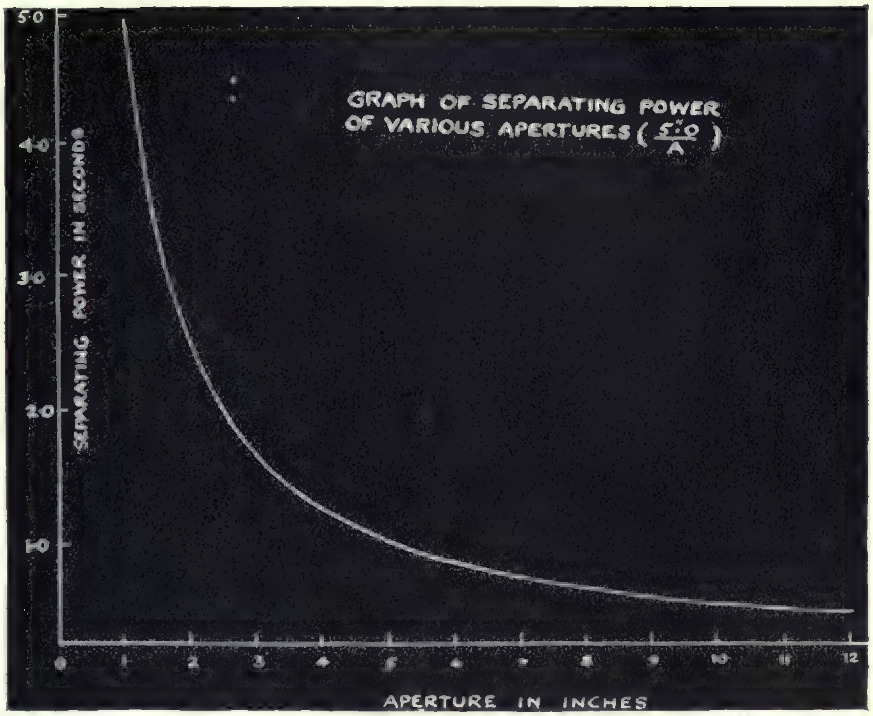
Another method of observing the Sun will be often found very convenient and effective. If a telescope is directed to the Sun, and a sheet of white card held at a little distance from the eyepiece, an image of the Sun will be found projected on it, which may be rendered sharp and distinct by adjusting the eyepiece in the usual way. An eyepiece of low power should be used, so that the whole of the Sun's disc may be included in the field, and even some of the finer details of the spots may be well seen in this manner. The magnification obtained in this way depends on the power of the eyepiece and on the distance of the screen from it ; as a rough guide, it may be said that with an eyepiece which would normally give a power of fifty diameters, and a screen at twenty inches from the eyepiece, the image of the Sun will be about nine and a half inches in diameter. It is advisable to have the screen well shaded, or the brilliancy of the image will be lost. Webb ("Celestial Objects," I. 36–7) remarks on this point : "Noble has found that plaster of paris, smoothed while wet on plate-glass, gives a most beautiful picture : he fixes a disc of it inside the base of a pasteboard cone, blackened within, one foot long and six inches across the large end, the small end being opened so as to fit close on the eyepiece, with a hole in the side of the cone to look at the image."



[*M. A. Ainslie.*

PROJECTION OF SUN'S IMAGE ON A SCREEN.

The image is formed as usual between the lenses of the eyepiece (here supposed of the Huyghenian form), and the eye lens projects an enlarged image on the screen. In the figure only the rays from the lowest point of the Sun's disc are shown : every other point of the image is, of course, similarly projected. Note that in order to focus the rays on the screen they must be convergent on leaving the eye-piece instead of parallel as is usually the case ; the eyepiece has therefore to be slightly withdrawn from the object glass as compared with its normal position.



M. A. Ainslie.

CURVE OF SEPARATING POWERS OF VARIOUS APERTURES.

This curve shows the angular separation of the closest double stars that can be separated by object glasses or specula of various apertures: it is based on the formula 5″.0 /Aperture in inches. This is pretty near to the truth for stars of moderate brightness as seen in the telescope, but should be somewhat decreased for fainter stars, and increased for brighter.

This method of observing the Sun has, at any rate, the advantage that it is available for several persons at once, but it does not give quite the same view of minute detail as is to be obtained by direct vision. It is also as well to give a word of warning: the writer has found on more than one occasion that the eyepiece tended to become discoloured by the intense heat concentrated on it. If a 5-inch telescope is directed to the Sun on a bright summer day, and a piece of paper held at the eyepiece, it is at once ignited, and the observer will find that he can conveniently light his pipe in this way! Thus, if the projection method is much employed, it is as well to reserve an eyepiece for this purpose only.

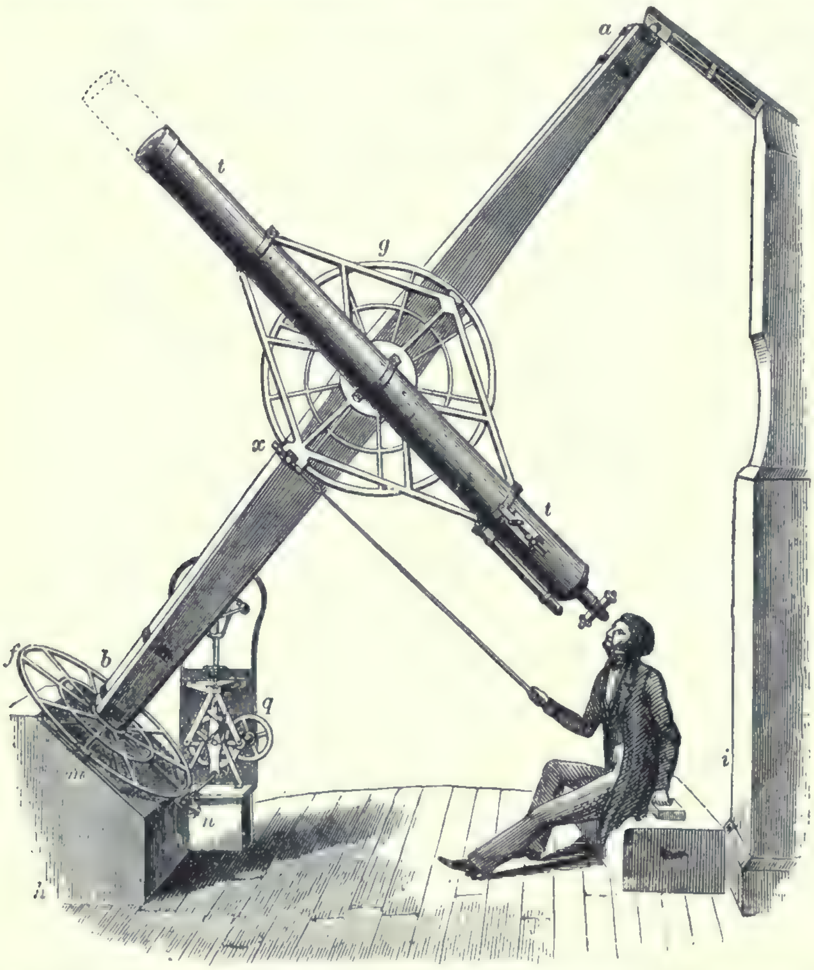
Probably the chief use of this method, apart from obtaining general views of the number and size of the spots and faculae is that their position on the Sun may be obtained with considerable accuracy. Discs may be obtained marked with the solar meridians and parallels for different times in the year: if the image is received on one of these, the positions of spots may at once be recorded. Seeing, however, that photographs of the whole solar disc are daily taken at Greenwich and other observatories, it may be doubted whether the amateur will find it worth his while to make such observations.

Probably the amateur's work on the Sun will lie in the direction of the observation and drawing of the finer details of spots. It is true that photographs of these are taken in great numbers, but as a rule even the best photographs fall far short of good drawings in the amount of detail shown, and there is plenty of work here for a good draughtsman. The recording of the number and position of the prominences on the limb is also work suitable to the amateur possessing the necessary spectroscopic appliances.

Coming now to the Moon, it may be said that although photography has furnished accurate determinations of the position of the various features upon the lunar disc, it has by no means rendered eye-observation obsolete. Even the photographs taken with the Mount Wilson 100-inch probably the finest lunar photographs that have as yet been obtained do not show all the detail capable of being seen by a practised eye with an eight-inch telescope. The observer who follows the appearance of special craters or other features with the view of detecting any instance of change during the lunar month, needs to make repeated and careful drawings of the finest details his telescope is able to show. For such a purpose visual observation is certainly more efficient than photographic, and well within the resources of the amateur. Long continued observation of the Moon, especially with low powers,

is apt to be rather trying to the eyes, and to impair their efficiency on other fainter objects; the benefit of one or two screens of neutral-tinted glass of various depths, to fit on the eyepiece, will soon be appreciated by the observer. The possessor of even a small refractor will find much interest and enjoyment in studying and identifying the general features of the lunar surface, as shown on a good map, while for eclipses, solar and lunar, a small refractor is probably the best instrument.

The planets offer a splendid field for amateur energy. At the present time the amateur has this field of observation almost entirely to himself, for, with few exceptions, the planets are left alone by the principal observatories, who have as much as they can do with other work. But to be of any service to Astronomy, observation of the planets must be systematic and carefully recorded: occasional drawings or notes of some unfamiliar detail are not sufficient, though not without importance at times. Most recent observations of Mercury and Venus—both difficult planets to observe satisfactorily, and often better seen with small telescopes—have been devoted to the endeavour to throw light on the vexed question of their axial rotation-periods. Few definite markings have been seen on their surfaces, and these planets are perhaps the most difficult of any (with the exception of Uranus and Neptune) for the observer. A fairly high power must be used, but not so high as to lose sufficient contrast. Of course, steadiness of the atmosphere is all-important, though it is not usually found in the daytime. Mercury is best observed in twilight, so long as his altitude is sufficient—conditions not easily found—and Venus in daylight, since even in twilight her intense lustre renders the detection of delicate markings extremely difficult.



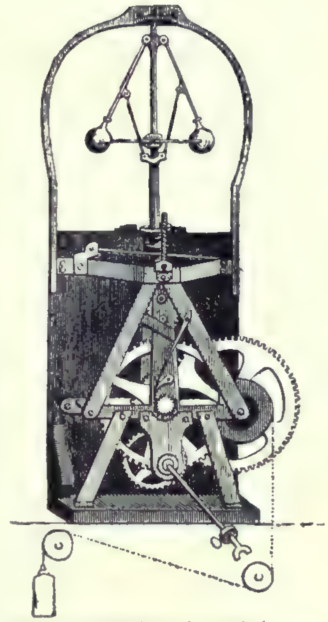
From "Descriptive and Practical Astronomy," by G. F. Chambers. *By courtesy of The Clarendon Press.*

"ENGLISH" EQUATORIAL REFRACTOR.

A moderate-sized refractor mounted on a typical "English" stand of the early years of last century. *a b* is the polar axis; *t* the telescope tube; *h* and *i* the piers on which the polar axis is carried; *g* is the declination circle, and *x* the slow motion in declination; *f* is the circle showing hour angle or right ascension, read by a vernier at *m* and driven by the clock *q* by means of a tangent screw at *n*; the dotted lines at the object glass end of the tube indicate the position of the dew-cap. The observer, who is using a micrometer, is shown controlling the telescope in declination by means of the slow motion.

Mars, Jupiter, and Saturn are far more satisfactory objects for amateur research, and a telescope of fair aperture—*e.g.*, a 6-inch refractor or an $8\frac{1}{2}$-inch reflector—is capable of much

useful work on these objects. Mars usually exhibits his details best under a rather high power: not less if possible than 300, although such a power demands fairly good atmospheric conditions. Jupiter as a rule is best seen with rather lower powers, such as 200 or 250, although on occasion the atmosphere is sufficiently steady to admit of much higher powers being employed, 350 or more. Saturn, for some not easily explained reason, usually stands magnifying better than Jupiter: but his disc is so much less luminous than those of either Mars or Jupiter that little is gained by increase in power. The surface markings of these planets have already been fully described in former chapters; all that need be said here is that the observer should take the utmost care not to let himself be biassed, in the objects he represents on his drawings, by any preconceived theory—and this is especially the case with Mars, on account of the great amount of controversy and discussion that has centred around the famous and elusive so-called "canals," and largely the result of this unfortunate mistranslation of the Italian word *canali* used by their discoverer Schiaparelli. In fact, it is most important, when observing and attempting to draw these planets, to represent only the details that are *certainly* visible: and it must be mentioned that—especially on Mars and Jupiter—many details have found their way from time to time into the drawings made with small telescopes, which are not to be seen with really adequate instruments. On Mars, the work of the amateur will chiefly be the recording of changes in the relative brightness and colour of the markings, and of any variations in their outline, seasonal or otherwise. The observer of Jupiter has a wide field open to him in the study of the ever-changing belts and zones, and in recording the times of transit, over the central meridian of the disc, of bright and dark spots and other irregularities, with a view of determining the periods of axial rotation in different latitudes.



From "Descriptive and Practical Astronomy," by G. F. Chambers. [*By courtesy of The Clarendon Press.*

SIMPLE FORM OF DRIVING CLOCK.

This illustration of a simple driving clock shows very well the principle on which the clock works. The motion, which has to be continuous, is controlled by a governor similar to that of a steam engine.

COL. E. E. MARKWICK, C.B., C.B.E.

Col. Markwick was for many years Director of the Variable Star Section of the British Astronomical Association, and the Memoirs of that section are proof of the value of his services to Astronomy. Most of his work has been done with an eight and a half inch altazimuth reflector. Col. Markwick has also been President of the B.A.A.

In this connection it may be as well to say a few words as to the system now adopted for the recording of the longitudes of Jupiter's spots, etc. As has already been mentioned earlier in this book, the rotation periods of spots on the surface of Jupiter fall into two well-defined classes—long and short. The equatorial regions of the planet perform one revolution on an average in 9h. 50m. 30s.: the rest of the planet's surface lags behind the equatorial

THE "PILLAR-AND-CLAW" STAND.
This illustration is inserted as a warning. The stand shown is about as inefficient as a stand could be. The only thing that can be said for it is that it looks neat and is cheap; for practical work its want of balance and stiffness of motion render it useless.

regions to the extent of rather over five minutes, performing a rotation, on an average, in 9h. 55m. 40·6s. These values, although they may differ from the rotation-periods of individual spots, are taken as standard, and two systems of longitude are based on them: System I for the equatorial regions and System II for the rest of the disc.

The "prime," or "zero," meridians of these two systems are supposed to swing round the planet's axis uniformly, and the times at which they are on the central meridian of the disc are predicted in the Nautical Almanac, and in the annual "Observers' Handbook" of the British Astronomical Association. In addition, the longitude of the central meridian, or line from pole to pole bisecting the disc, on both systems is predicted for definite hours of Greenwich Mean Time daily throughout each apparition of the planet. From these data the rotation period of any given spot is easily determined: for if two times of its transit over the central meridian of the disc are recorded at a sufficiently long interval, the longitude of the spot at the time of either observation may be deduced from the predicted time of transit of the appropriate zero meridian (System I for equatorial, II for other spots) compared with the observed time of transit. Any change of longitude in the interval between the two observations must be the result of a slight difference of the rotation period of the spot from the standard rotation period of the system adopted: and a simple calculation will show what the rotation period must have been to produce the observed change of longitude.

Tables facilitating these calculations will be found in the publications mentioned, with the exception of the Nautical Almanac: and it will generally be found easier and quicker to deduce the longitude of a spot by means of the tables giving the longitude of the central meridian for a specified G.M.T. If the difference between this G.M.T. and the observed time of transit is taken, it may be, by means of the tables, at once converted into difference of longitude: this difference applied to the predicted longitude of the central meridian gives at once the longitude of the spot at the time of observation.

The accurate determination of the time of transit of a given spot over the central meridian is a matter requiring some care if reliable results are to be obtained. Some few observers have obtained excellent results by means of the micrometer: the distance of the spot from the limbs being measured from time to time, and the time of transit deduced. Most observers, however, prefer to make careful estimates by eye only, and in this particular class of observation eye-estimation seems to give quite as accurate results as measurement.

The motion of Jupiter's spots in the neighbourhood of the central meridian of the disc is surprisingly rapid: an interval of two minutes is sufficient to cause an alteration in the position of a spot in the disc quite obvious to an experienced eye: and the method of simple eye-estimation has the advantage that many more transits can be observed on a given night than is the case with the micrometer method.

Observers of Jupiter will also find considerable interest in the variations of colour of the various belts and zones: these should be carefully recorded, as it is quite possible that they may be periodic,

and possibly dependent on the position of Jupiter in his orbit round the Sun. In particular, the great belts bordering the equatorial zone on its northern and southern sides have of late years exhibited from time to time a marked display of strong red colour, often accurately described by the expression " fiery." In such observations the reflector is unquestionably to be preferred to the refractor.

The amateur who is in possession of a telescope of sufficient power will find it worth his while to examine closely the appearance of the discs and shadows of the satellites when in transit over the disc, and also the appearance of the discs of the satellites (especially the third and largest, Ganymede,) when clear of the planet. Many irregularities have been noted in recent years by Phillips, Steavenson, and others, but it must be said at once that such observations are only suited to instruments of considerable aperture: nothing smaller than an 8-inch aperture is of much use, except possibly to very keen and experienced eyes.

Small telescopes—even the modest 3-inch—will, if of really first-rate quality, show much in connection with Jupiter that will interest the amateur. With a 3-inch, the belts are well seen, as well as the oblate appearance of the disc : and the ever-changing arrangement of the four brighter satellites, together with their eclipses and occultations, and their transits, and those of their shadows, over the disc, will afford a never-ending source of pleasure. And it is not beyond the capacity of such small instruments to do really useful work : the records of the Jupiter Section of the British Astronomical Association abound in valuable observations, especially of the varying intensity of the belts, and even of some of their finer details, made with 3- and 4-inch refractors.

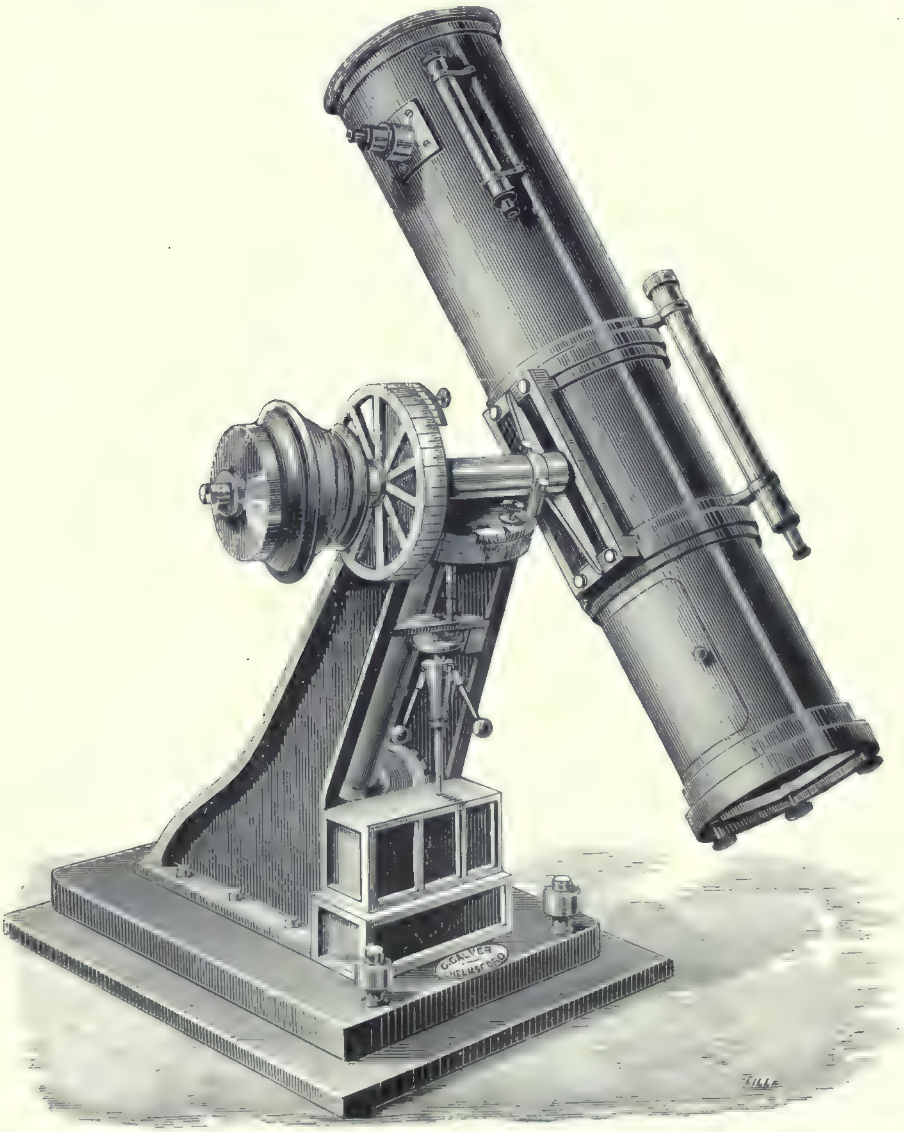
Saturn always presents a fascinating picture : possibly the most

By courtesy of *Messrs. Cooke, Troughton & Simms*

SMALL REFRACTOR ON ALTAZIMUTH STAND, WITH STEADYING RODS.

This is a very simple and efficient stand for a small refractor of from three to five inches aperture. Although no slow motions are provided, a star can be kept in the field of view without difficulty, after a little practice, with powers up to 150. The steadying rods, which, as will be seen, lengthen or shorten according to the position of the telescope, tend greatly to reduce vibration : their lower ends can be pushed into holes in any of the three legs of the stand, which is light and easily portable.

beautiful that the telescope has to show us. The ring-system, as well as Cassini's main division in the ring, is well seen with a 3-inch, and even the inner, or " crape " ring, is not beyond the capacity of a 4-inch under good conditions. Of course the details of the rings are more readily made out when the ring is " well-opened." Small instruments will also show the belts on the globe fairly well, and one or two of the satellites ; Titan, the largest, is visible with almost any telescope, though the others are much fainter. Still, three or four of them are not beyond the reach of a 4-inch. But for any serious work on this planet it is necessary to use much larger apertures : to obtain really critical views, not less than eight inches, and larger if possible. Encke's division in the outer ring—not always to be seen at all with any telescope —has been seen with a 6-inch refractor or an 8½-inch reflector : and for any study of the (sometimes anomalous) appearance of the shadow of the globe on the rings, or of the visibility of the globe through the crape ring, large apertures are certainly required, while when the ring is turned edgewise to the earth it disappears even in the largest instruments. At its last disappearance in November 1920, it was totally invisible to the present writer even in the Greenwich 28-inch refractor.



By courtesy of Mr. G. Calver.

LARGE REFLECTOR ON CLOCK-DRIVEN EQUATORIAL MOUNTING.

A typical " German " equatorial for large instruments : the tube rotates in a cradle, and has a door for the removal of the cover of the speculum.

The possessor of an instrument of adequate aperture will do well to watch the disc of Saturn closely for the appearance of any spots, bright or dark, by which the period of his axial rotation may be determined. Such spots have been rarely seen, and the rotation period is in consequence somewhat uncertain.

Beautiful as the spectacle presented by Saturn undoubtedly is, it must be admitted that there is a certain " sameness " about his appearance that is apt to grow somewhat monoto-

nous, and possibly for this reason the number of observers who at the present day make a systematic study of this planet is small. But it has been said that "nothing is so probable as the unexpected," and this, if true at all, is certainly true in Astronomy. To stimulate observation of this planet, perhaps the writer may be permitted to refer to his totally unexpected good fortune, shared by Mr. J. Knight, of Rye, in witnessing the passage of a seventh-magnitude star behind the outer ring on 9 February, 1917, the star being plainly seen through the material of the ring—this being the first occasion on which such visual confirmation of the transparency of the outer ring (required by theory) had been obtained. There is always the chance, to a systematic observer, that some important observation may be obtained when least expected, so that no object should be neglected merely because at first sight observations thereof seem likely to be somewhat monotonous.

By courtesy of] [*Messrs. Cooke, Troughton & Simms.*

SMALL ALTAZIMUTH REFRACTOR, WITH STEADYING RODS AND SLOW MOTIONS.

An improvement on the stand illustrated on p. 725; the steadying rods are retained, and slow motions in altitude and azimuth are added, these being well-designed to avoid vibration. This is a most efficient form of altazimuth stand for a small refractor.

Uranus and Neptune may be *seen* with a small telescope, but although Uranus presents a very perceptible disc, and Neptune one which is not quite so perceptible, that is about all that can be done with apertures less than about eight inches: the present writer has seen the belts of Uranus with a 9-inch reflector, and very plainly with a 10-inch refractor. Neither of these planets are really objects which greatly repay the trouble taken to look them up—especially Neptune—and little will probably be learnt as to their constitution until, as is much to be desired, one of the "giant" telescopes is devoted to a systematic study of them. In any case the highest power that the telescope is capable of giving will probably afford the best view, as the discs of these planets are so extremely small, 3·8 seconds of arc in the case of Uranus and 2 seconds in the case of Neptune.

From] [*The Philosophical Transactions*, 1793.

THE OLD-FASHIONED EQUATORIAL.

An Eighteenth Century instrument, showing the style adopted in those days. An instrument of this description was intended for the precise determination of positions of the heavenly bodies, and for this purpose the circles (nowadays used only for setting the instrument on an object) were made very large. The equatorial has long been discarded for this purpose, precise determinations of position being now made with the "transit circle."

For the observation of Comets, low powers and large apertures are a necessity, except for large and conspicuous comets—of which there has been a remarkable dearth for many years—which are best observed with small binoculars, or even by the unaided eye. Those amateurs who make systematic search for new Comets need to be acquainted with the small nebulæ which are scattered in profusion in various parts of the sky. Comets at their first appearance look just like faint nebulæ, and only their motion together with knowledge of the nebulæ will serve to differentiate them, though as the Comet nears the Sun and grows brighter, the "celestial visitant" takes on, as a rule, a more typical aspect. The details of Comets' tails and appendages are so much better depicted by photography than by eye-observation that there is really little scope for the latter.

For the observation of Meteors, of course, no telescope is required. The equipment of the observer of these bodies may be summed up almost in two words: enthusiasm and patience. Here, as in all branches of amateur observation, co-operation of observers is highly desirable: for the determination of the "real paths" of Meteors it is essential. The observer of Meteors cannot do better than become a member of the Section of the British Astronomical Association devoted to their study; the same may indeed be said of any other branch of amateur observation.

To turn now to the sidereal heavens, it may be said that the number of objects presented to the amateur's gaze is somewhat staggering: what useful work is there to do? Probably the most promising field of work for the amateur of ordinary means and equipment is the study of variable stars, in which, indeed, amateurs have done by far the greater part of the work. The observations of the Variable Star Section of the B.A.A. number several thousands already, and their number is added to by thousands yearly. For this type of work almost any telescope, however, can be of service: even a little binocular will do excellent work on the brighter variables, for which indeed it is better than a larger telescope. Of course the fainter the star to be observed, the larger must be the aperture employed, and probably it may be said that the most effective telescope of all, that can be obtained at a cost suited to most amateurs, is a reflector of about 8½ inches aperture. To mention one name only, most of the extremely valuable work of Col. E. E. Markwick on variables has been done with a reflector of this aperture, and much good work has been done with smaller instruments. In the study of variable stars experience and knowledge of the sky count for a great deal, and it would take up too much space to give here any detailed rules for the observations of these objects. Fortunately amateurs are in this matter very well looked after by the Variable Star Section of the British Astronomical Association, of which any intending observer of variables should most certainly become a member.

The measurement of double stars is rather beyond the amateur of moderate means, since the work is probably better done with a refractor than with a reflector, and refractors suitable for the purpose—not less than eight inches in aperture, and equatorially mounted with driving clock and micrometer—

THE STARS FOR FEBRUARY.

Our plate shows the aspect of the sky as seen, looking North and South, from Westminster Bridge; but the positions of the stars will be practically the same for any place in the Latitude of Great Britain.

The constellations will appear in the positions shown on February 1 at about 11.30 p.m. (Greenwich Mean Time.)

„ 8 „ 11.0 p.m. „ „ „

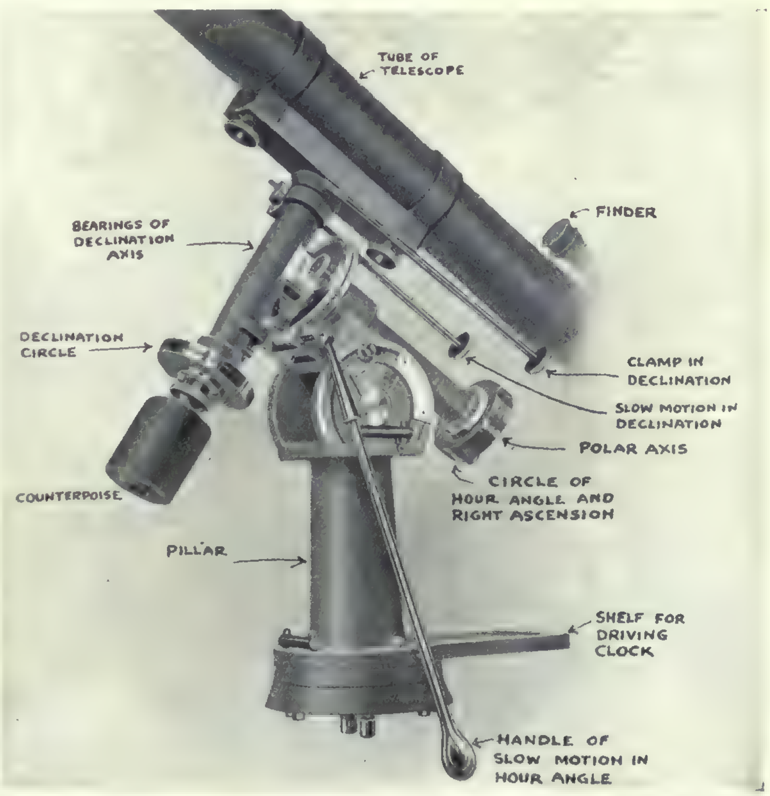
are extremely costly: indeed £500 may easily be spent on an instrument of quite moderate size. Possibly some of the more widely separated pairs may be measured with small instruments, say down to 4½ inches, but it is open to doubt whether the accuracy of such measures is such as to render them of much value. Few amateurs—though it must be said that there are notable exceptions—have done much with the reflector in this branch of observation. Reflectors as a rule are not so effective on stars with high powers as refractors, although in other branches of work they fully hold their own.

Now that such great advances have been made in our knowledge of Nebulæ and Clusters by means of photography, there is probably little left for the amateur to do on such objects, although from the æsthetic point of view it may be said that some of the brighter of these are exquisite objects even for small telescopes. But since no eye, even with the largest telescope in existence, will ever see a tenth of the structure that is revealed in nebulæ by photography, there does not seem much scope for amateur energy.

Star-colours, and especially any variations they may suffer, present an interesting field for observation; and here, as in all estimates of colour on any heavenly body, the reflector is beyond question better than the refractor, and its indications much more trustworthy. But mere estimates are of little use, and some system of comparison tints that can be easily referred to should certainly be adopted: observers often differ to a surprising extent in the names they give to the colour of the same star, and such expressions as "pale yellow," "tawny," "flushed white," and so on, may indicate the observer's impressions at the time of observation, but afford little information to others. It is better, if some peculiar tint is to be recorded, to compare it to some well-known natural object—*e.g.*, "sea-green," "claret," "steel-blue," etc., are better—but beyond question colours should be compared with definite standards in the spectrum, and at all times allowance should be made for the very considerable difference in the appreciation and estimation of colour by different eyes.

Photography of the stars—if we except the production of convenient charts of portions of the sky on a small scale—is beyond the resources of the amateur, unless he can afford the very expensive appliances requisite, and this work is now done on so extensive a scale at the great observatories, that it is hardly worth the amateur's while to attempt much in this line. The amateur may perhaps produce interesting pictures of the Moon on a small scale, and possibly of large sunspots, but where the ground is already so well covered, it is rather a waste of time for the ordinary amateur to compete.

The same may be said, and perhaps with even greater



By courtesy of] [*Messrs. W. Watson & Sons.*

DETAILS OF "GERMAN" EQUATORIAL STAND.

A view of a typical "German" equatorial stand for a small refractor, showing the various details. This stand is intended to be mounted either on a pillar or on a tripod

truth, with regard to the spectroscope. It is true that with a small direct vision spectroscope applied to the eyepiece of a telescope of fair aperture (the Zöllner form is perhaps the best) very pretty views of the spectra of the brighter stars may be had, and the various main types of spectrum recognised, but for any advanced work—in which the camera has now completely superseded the eye—the instruments are very costly and the skill required very great for effective work. At the same time it is possible sometimes that visual observations of the spectrum of a nova soon after its appearance may be of service to science; and the amateur might do worse than include some inexpensive form of star spectroscope in his equipment.

By courtesy of *Messrs. Cooke, Troughton & Simms.*

SMALL EQUATORIAL REFRACTOR ON WOODEN TRIPOD, WITH DRIVING CLOCK.

Although a driving clock is not as a rule fitted to a portable stand of this description, there is no doubt that it is a great convenience. The stand illustrated has most of the refinements of the large stands on iron pillars, but to obtain the full advantage of the clock and divided circles it would be necessary to adjust the polar axis carefully, so that the stand would really cease to be portable. The dew-cap with its covering flap may be noticed, as well as the screws for "squaring-on" the object glass.

The beginner in astronomical observation often finds a difficulty in deciding what magnifying power is best to employ on a given object. As a rule he is inclined to use much higher powers than are either necessary or expedient. A certain amount of *light* in the image is always required if the details present are to be well seen, and although with a good telescope on a really good night the image of, say, Jupiter may remain sharp and clean-cut with quite high powers, it does not follow that these will really exhibit any more detail than can be well seen with lower powers. A statement that has been copied from book to book is to the effect that good telescopes will bear a power of 100 per inch of aperture; this, except perhaps on very exceptional occasions, is far beyond their capacity, and no amateur need be in any way disappointed with his instrument if *on an ordinary night* he finds that anything higher than about 30 to the inch gives a poor view, no matter what the object. For the resolution of close double stars the magnifying

power may occasionally be carried with advantage as far as 50 or 60 to the inch. With such a power a good telescope will perform any resolution required down to the theoretical limit to be referred to later. On the Moon and planets much lower powers are desirable, though small telescopes will stand a somewhat higher power, proportionally to their aperture, than large ones. The following table exhibits, for two selected apertures, the powers which will be most generally found useful with various classes of object; the apertures selected are fairly representative of those usually found in amateur hands.

	4-inch Refractor.	*8½-inch Reflector.*
Comets	30	40
Nebulæ and clusters...	40	60
Variable stars ...	40	60
Sun	60	100
Moon and planets (general views)	80	120
Moon and planets (details)	100 to 180 (150 as an average)	160 to 300 (240 as an average)
Wide double stars ...	100	160
Close ,, ,, ...	200 to 250	300 to 400
Faint companions to stars	80 to 100	120 to 160
Occultations of stars by the Moon	60	100
Lunar eclipses ...	40	40

The above must only be taken as a rough guide: observers differ to a considerable extent in the powers they use, but the above will not be found far wrong as a general rule. Occasionally the planets, especially Mars and Saturn, will bear higher powers than those above indicated: the writer has found a power of 367 on a 9-inch reflector occasionally give excellent views of Jupiter, as well as the others, but in systematic observations of Jupiter extending over several years he has, with this aperture, almost always used 270 on good nights, and 180 when the "seeing" was comparatively poor. The writer's drawings of Jupiter on pages 343 and 348 were all made with 270 on a 9-inch reflector, and they do not by any means claim to represent all the intricate detail visible at the time.

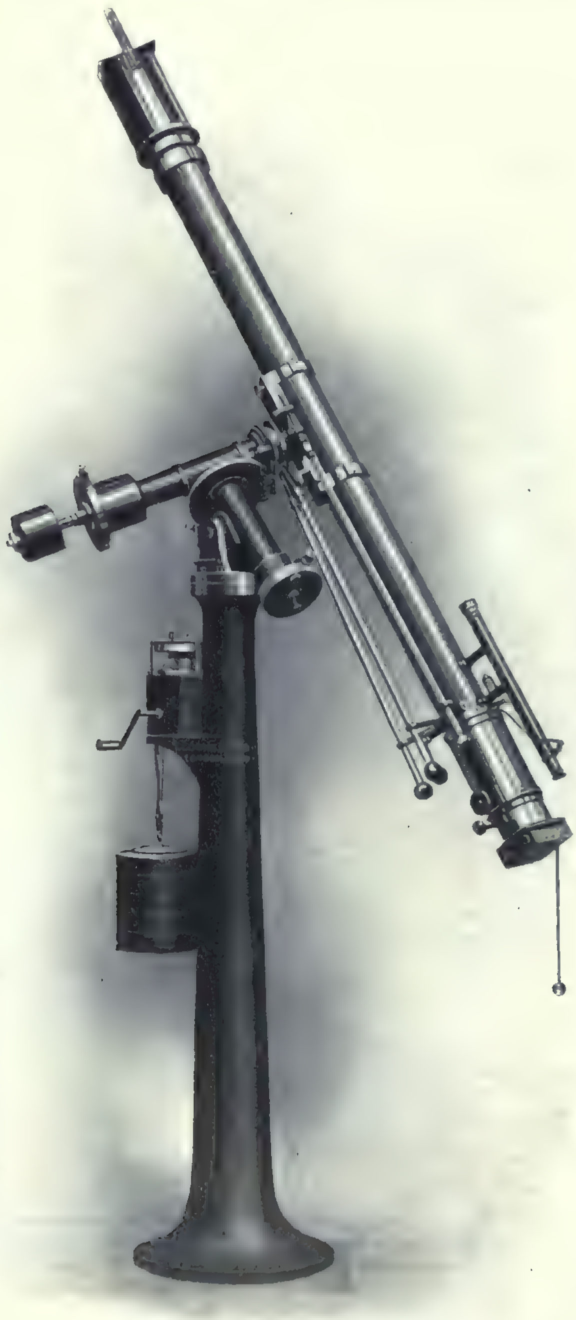
By courtesy of] [*Messrs. Cooke, Troughton & Simms.*

SMALL REFRACTOR ON PORTABLE EQUATORIAL STAND, WITH SLOW MOTIONS.

A very convenient and efficient form of mounting for a small instrument, not exceeding about four and a half inches in aperture. The handle hanging down operates the slow motion in hour angle, and the two handles attached to the tube are one for moving, and the other for clamping, the telescope in declination.

High powers suffer under a great disadvantage, quite apart from the dimness of image due to the dilution of the available light and the falling off of definition due to atmospheric disturbance and optical defects; any vibration of the telescope, due to unsteadiness of the stand or to wind, is much accentuated; and the observer who is not provided with a driving clock—a convenient luxury, but by no means an essential to good observation—will find the following of the object rendered difficult

by reason of the small field of view and the rapid motion of the object across it. To quote Webb's words ("Celestial Objects," I. 16), "the student will soon learn to reserve it" (a very high power) "for special objects and the finest weather, when it will sometimes tell admirably." He adds, very truly, "Experience in all these matters is the surest guide."



By courtesy of] [*Messrs. Cooke, Troughton & Simms.*

FIVE-INCH "PHOTO-VISUAL" REFRACTOR, MOUNTED ON FIXED EQUATORIAL STAND, CLOCK DRIVEN.

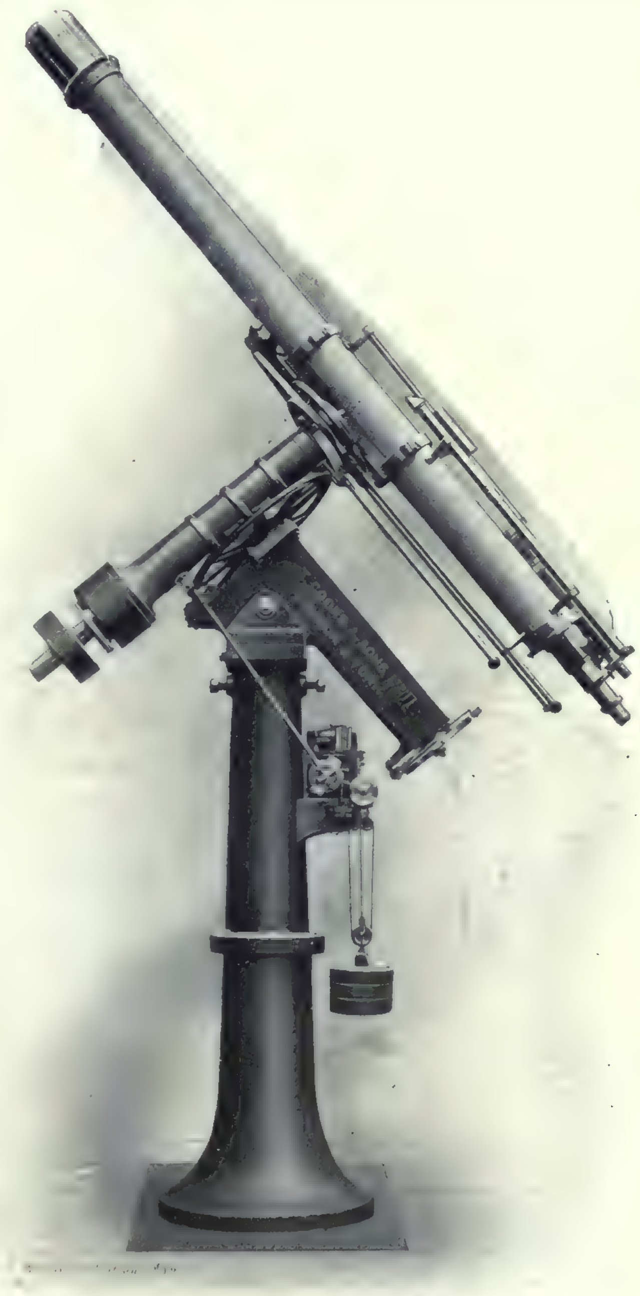
In this instrument a plate-holder is shown in position, so that the telescope is converted into a camera. Here again the slow motions are brought to the eye end, and conveniently placed for the observer to control the following of the object to be photographed.

The reader may very possibly ask why, seeing that the magnifying power of a telescope depends on the focal lengths of object-glass (or mirror) and eyepiece—it is, in fact, the ratio of the two—it should not be possible to obtain any power desired. In theory it is perfectly possible to do so—for example, a 4-inch object-glass might easily be made with a focal length of 10 feet, and an eyepiece could equally easily be made with focal length one-tenth of an inch. This would give a magnifying power of 1,200 diameters. All this is perfectly true, but such a power would be quite useless on such an aperture. Quite apart from the fact that the image of a planet with such a power would be extremely faint and unsatisfactory, there is a definite limit to the power of an object-glass to render fine detail, or to show as separate the two components of a double star, which depends on its aperture and on nothing else, quite apart from the optical quality it may possess.

Without going into the mathematical reasons for the statement, it may be said that, in theory, luminous points, such as the components of a double star of average brightness, can be separately seen with a telescope, if their apparent distance apart is not less than $5\frac{1}{2}$ seconds divided by the aperture of the telescope in inches. The celebrated observer W. R. Dawes put the limit, from actual trial,

somewhat lower. His figure was 4·56 seconds, divided by the number of inches in the aperture. But neither the theoretical nor the Dawes limit can be taken as exact, as the separation or otherwise depends on the diameter of the minute "spurious" disc which is the telescopic image of a star; and this diameter, as seen by the eye, depends to a large extent on its brightness.

This "spurious disc" deserves a few words of explanation. On the ordinary geometrical theory, in which light is supposed to travel in straight lines, called "rays," the image of a mathematical point—*i.e.*, something having no size—will be a similar mathematical point. This idea is convenient for tracing the path of rays of light through lenses, mirrors, and so on, but it is far from representing the actual facts. On the now universally accepted wave-theory of light, which has already been explained in Chapter I, the image of a mathematical point will be a somewhat complicated pattern consisting of a central bright disc surrounded by alternate bright and dark rings due to diffraction, these bright rings growing fainter as their diameter increases. The diameter of the *first dark ring* can be accurately computed, but the central disc has *no well defined edge*, its illumination falling off steadily from the centre to the first dark ring. It thus follows that the diameter of the central disc, *as seen by the eye*, will depend upon the brightness of the luminous point—of the star, in fact—as well as on the aperture of the telescope. In obtaining the theoretical limit of 5½ seconds divided by aperture in inches quoted above, the *visible* diameter of the central disc was taken as *half* that of the first dark ring. This is supposed to be for an "average star"—a rather loose expression—and the separating power of the telescope will be



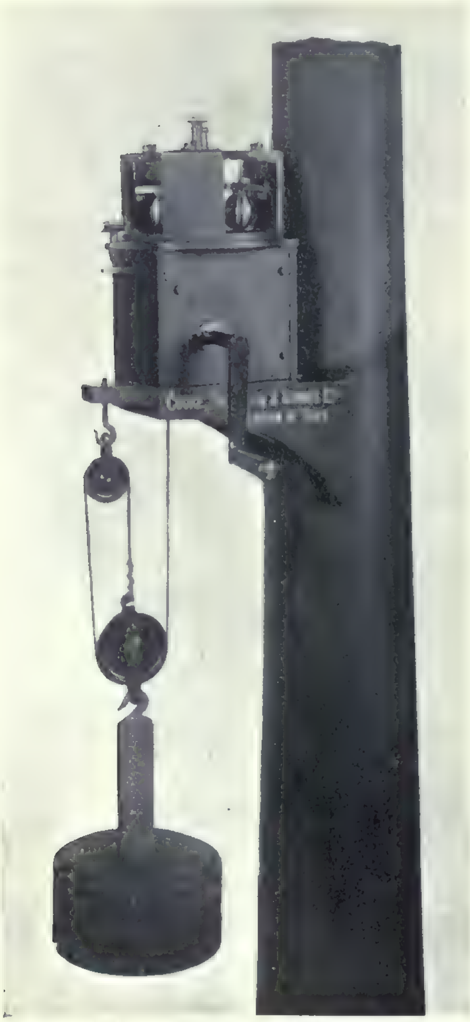
By courtesy of *Messrs. Cooke, Troughton & Simms*

REFRACTOR ON FIXED EQUATORIAL STAND, WITH DRIVING CLOCK.

An instrument of moderate size well suited to amateur requirements, intended to be housed in a small observatory. Several refinements are here introduced, the slow motions being brought down to the eye end of the tube, and the declination circle read by a small telescope (shown to the right of the tube) from the eye end.

rather greater on faint stars, on account of their smaller discs, while bright stars will be less easily separated; since for the separation of two equal stars, the centre-to-centre distance between their discs must be not greater than the diameter of either. As a rule, it is only round very bright stars that more than one diffraction ring can be seen; with faint stars no ring whatever is visible, except under exceptional conditions.

Perhaps we may say, to strike a fair average, that something between the " theoretical " and the " Dawes " limit will represent the mean state of affairs, and we shall not be far wrong if we take the limit of separating power of a given aperture as 5 seconds divided by aperture in inches, although it is only fair to say that many experienced observers place the limit somewhat lower; even lower than the " Dawes " limit.



By courtesy of] [*Messrs. Cooke, Troughton & Simms.*

MODERN DRIVING CLOCK FOR A TELESCOPE OF MODERATE APERTURE.

A good example of present-day practice. The clock is shown on the shelf provided for it on the pillar of the stand, and it will be seen that the " governor " is modified in detail, though its principle remains the same as in the earlier forms. The rate of the clock can be adjusted by means of the vertical screw shown on the left.

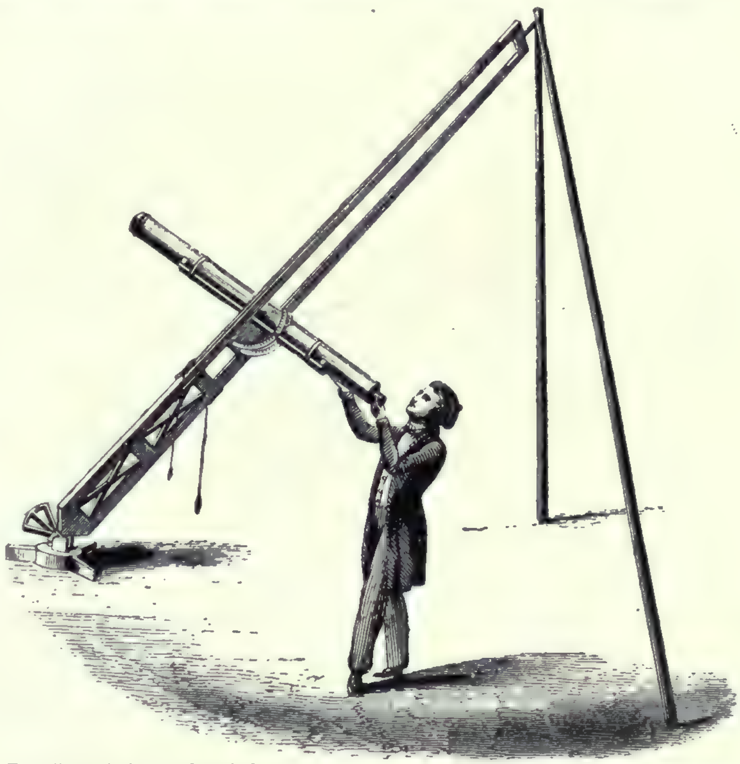
It thus follows that a 10-inch aperture should, if good, and under good conditions, just separate two equal average stars at half a second separation, and that 5 inches is the smallest aperture that will divide a double star of one second. But these values, it must be remembered, are only averages, based on certain assumptions which may not be more than reasonable approximations, and the dividing power of a telescope is somewhat less on bright stars than on faint, owing to the larger discs given by the former. As a practical instance, it may be mentioned that the 9-inch reflector of the present writer has nicely separated the components of the star known as γ^2 Andromedae (a well-known test), the magnitudes of which are $5\frac{1}{2}$ and $6\frac{1}{2}$, and whose separation at the time was 0·57 second. This agrees pretty well with the formula for the dividing power of that aperture. Owing to the difference in brightness of the components, the discs were of perceptibly different sizes, so that the star looked, as a friend of the writer's remarked, " like a nice little blue loaf of bread."

Although in the above the ability of a telescope to show two adjacent stars as *separated* has been considered, it must not be thought that it is not possible to recognise the double nature of a star at separations well below the limit given by the formula. On a really good night, and with a first-rate telescope, it is often possible to see two stars individually, even though not completely separated; their " spurious discs " may overlap to a considerable extent, and may even only betray their separate presence by a slight " notching " or even by a slight elongation of the normally circular disc. It is recorded of the celebrated double star observer, the late Professor S. W. Burnham, that with a six-inch refractor—the dividing power of which would be of the order of about 0·8 second—he was able to detect the double nature of pairs whose separation was as small as 0·4 second, by the peculiar appearance of their images. But such observations require not only a first-rate night and instrument, but a very keen and experienced eye.

The above observations apply, *mutatis mutandis*, to the limits of the power of a telescope to render visible *any* fine detail ; for the image of an extended object—such as the disc of a planet—is formed by the integrated effect of the spurious discs of every point in the object. Hence, increase in magnifying power, unless accompanied by increase in defining—that is, resolving—power, is of little service ; it merely results in giving, as it were, a coarser texture to the image, and in rendering hazy and ill-defined the details which are seen sharply and clearly with a lower power.

A telescope, to be effective for astronomical observation, must be properly mounted, and much ingenuity has been devoted to the design of stands. Evidently, in order that the telescope may be directed to any part of the sky, it is necessary that it should have two motions, about axes at right angles (or nearly so) to one another. Now, there are two ways in which these axes may be placed ; one, which is generally known as the " Altazimuth " method, employs a vertical axis, to which is attached at right angles, and therefore horizontal, another axis carrying the telescope. This is a simple and useful way of mounting a telescope, and if well designed, allows of easy manipulation of the instrument. The other method, which is called the " Equatorial," or sometimes, in old books, the " Parallactic," is a natural development from the Altazimuth.

Consider for a few moments the apparent motions of the stars in the sky. If the observer will watch for a short time on a clear night, he will notice that the sky, as a whole, seems to rotate round a point which remains fixed: this point is where the earth's axis, if produced, would cut the celestial sphere—assuming this for the moment to be a solid material sphere at a very great distance from the observer. A little thought will show that this is so, since the apparent diurnal motion of the celestial sphere from east to west is due to the rotation of the Earth on its axis from west to east, and therefore must be performed about the same axis. The northern extremity of this axis, called the North Celestial Pole, is situated at an elevation above the horizon equal to the latitude of the observer, and is marked by a bright star (the Pole Star, Polaris) which is distant rather more than a degree from the true Pole. This applies to the position of an observer in the northern hemisphere ; if he is in the southern hemisphere, the South Pole of the sphere is similarly elevated, and appears to be the centre of rotation. There is, however, no conspicuous star marking the South Pole.



From "Descriptive and Practical Astronomy," by G. F. Chambers.] [*By courtesy of The Clarendon Press.*

THE " PARALLACTIC LADDER."

This quaint old drawing shows a simple form of " English " equatorial applied to the mounting of a small refractor. This method of mounting, however, is not very well suited to refractors, since the very long polar axis (the inclined frame on which the telescope is carried) tends to vibration.

A little consideration will now show that since the heavenly bodies, in the main, retain their relative positions, they will also remain at an unvarying angular distance from the Pole. This is almost exactly true for the stars, and since the Sun and planets only change their positions at a rate very

small compared to that of the diurnal rotation, it is approximately true of them also—even of the Moon, although the alteration of her position in the course of a night is very evident.

If, then, we take the vertical axis of the Altazimuth stand, and place it so that it is parallel to the Earth's axis, and therefore pointing to the Pole, it will be found that when we have a star in the field of view of our telescope, the axis which was formerly horizontal will not need to be rotated in order to follow the star, for if the telescope is kept at a constant angle with the other axis, its motion will just suit that of the star, which can therefore be kept in the field of view by rotating this axis only. The axis which was formerly vertical is now elevated to an altitude equal to the latitude of the observer, and is now called the "Polar Axis"; the axis which was formerly horizontal, but which is still at right angles to the Polar Axis, is now called the "Declination Axis," for if we attach to it a circle divided in degrees, minutes, etc., we can measure the "declination" (that is, the angular distance north or south of the Celestial Equator) of any object to which the telescope is directed. Similarly, a divided circle attached to the Polar Axis, and rotating with it, may be used to determine the "Hour Angle" through which the telescope has to be swung round from the meridian in order that the telescope may be directed to the object.

Photo by] *[W. H. Steavenson.*

AN EIGHTEEN-INCH REFLECTOR ON A "PARALLACTIC LADDER."

This eighteen-inch reflector, (the speculum of which was made by the famous maker, G. With), was bequeathed to the British Astronomical Association by the late N. E. Green, a well-known planetary observer (*see page 305*). It is now at the Rev. T. E. R. Phillips' Observatory at Headley, near Epsom.

All objects in the heavens have their position fixed by two angles, analogous to latitude and longitude on the Earth. That which has just been called "Declination" evidently corresponds to latitude, and the other, called "Right Ascension," corresponds to longitude on the Earth, and is measured, like longitude on the Earth, from a fixed point on the Equator, which in the celestial case is one of the two intersections of the Sun's path (the "Ecliptic") with the Celestial Equator, and is called the "First Point of Aries."

MR. W. F. DENNING.

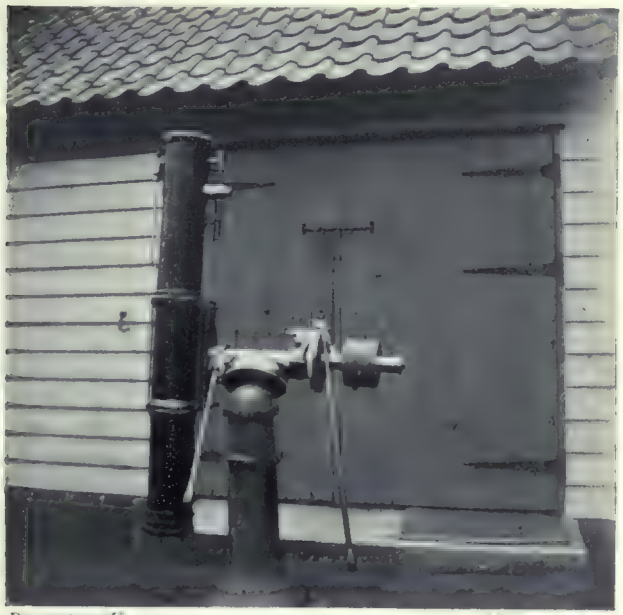
Mr. Denning's observations of planets and meteors earned for him the gold medal of the Royal Astronomical Society. For many years he has observed with a ten-inch reflector on an altazimuth stand, kept in the open air.

We see, then, one great advantage of the Equatorial form of stand, in that if we know the Right Ascension and Declination of an object—and these may always be obtained from catalogues or almanacs—we can, by a simple calculation and the help of a clock showing sidereal time, obtain the hour angle: the telescope may be set by means of the divided circles to the hour angle and declination, and if the Polar Axis is well adjusted, the object will be found in the field of view. The advantage of being able to find with certainty a bright object—such as Mercury or Venus—in the daytime is obvious.

But even if the stand is not fitted with divided circles, the single motion required with the equatorial stand is a great advantage, for since the rotation of the celestial sphere takes place at a constant speed, its motion may be exactly imitated, and the telescope kept directed to a star, by causing the Polar Axis to rotate continuously at the same rate; this may be easily done by means of a "driving clock," which, however—since the motion has

to be continuous—is usually controlled, not by a pendulum, but by some appliance very similar in construction and effect to the well-known " governor " of a steam-engine. Thus, the observer is relieved of the trouble of following the star, and can concentrate his whole attention on his observations. For spectroscopic and photographic work, the going of the clock has to be very accurately uniform ; and for such work, even the most accurate driving clock has usually to be supplemented by some form of additional control.

For ordinary work, which does not involve the use of the micrometer, spectroscope, or camera, a driving clock, though a great convenience, is by no means an absolute necessity : if the telescope is fitted with good " slow motions," it will be found that an object can be comfortably kept in view without any automatic help. And this applies to both forms of stand ; for after a little practice, the two motions required (in Altitude and Azimuth) for the Altazimuth stand, or the single motion (in hour angle) in the case of the Equatorial, become unconscious and automatic to an extent which would probably surprise those whose experience is limited to clock driving. Certainly an immense amount of valuable work has been done by means of Altazimuth stands, and it may be questioned whether, apart from the possibility of finding an object by means of the circles, there is any very marked advantage for the study of planetary markings, and most other purposes, in the equatorial mounting. These slow motions usually take the form, either of endless screws actuating worm wheels, or of ordinary screws and nuts, or of rack-work : they are a necessity if high powers are to be efficiently employed, and to be effective should be thoroughly good, sufficiently slow, and free from looseness and " backlash." In small equatorial stands of the present day, the slow motion in declination is often omitted, to the great detriment of their efficiency. Whatever form they take, the handles actuating them should be conveniently placed for the hand, and the clamps for throwing them in and out of gear should be easily accessible. These points are here mentioned because they do not appear to receive at the present day anything like the attention they deserve.



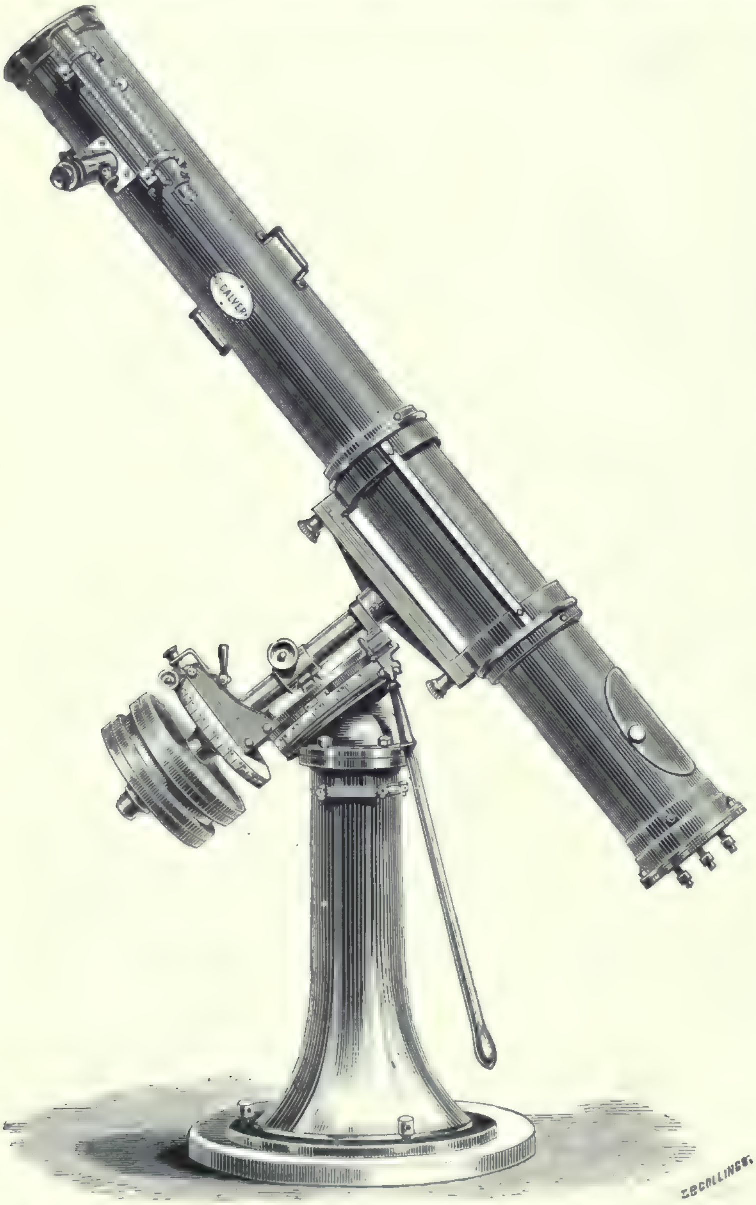
By courtesy of] [*Mr. G. Calver.*

EIGHT AND A HALF INCH REFLECTOR ON IRON PILLAR, WITH SLOW MOTIONS.

The cradle in which the telescope tube rotates is here well shown, and the two handles (in this case not brought to the eye end) controlling hour angle and declination. A telescope similar to this was used by the writer for some years, and proved most efficient and convenient. It was kept in the open air without the least detriment to its efficiency.

Even slow motions may be dispensed with if the powers to be employed are not very high. With a small telescope say a three- or four-inch refractor—it is quite possible, provided the instrument is properly balanced, so as to remain where it is put (as will be seen, a condition by no means always satisfied) to keep an object in view quite easily, once the necessary delicacy of hand and touch has been acquired. In the absence of slow motions, it is a great advantage to employ " steadying rods." These are made like the well-known " telescopic toasting-fork," and usually extend from the eye-piece end to some part of the stand : they tend to enhance the stability of the instrument in a wind. At one time the present writer employed a four-inch refractor so mounted (without slow motions) with great comfort, with powers up to 150. This form of mount, however, is hardly " the last thing in efficiency."

We may now consider the various types of stand, of the two forms that are to be met with, and commence with the Altazimuth as being the simplest. And here a word of warning is necessary at the outset. A stand known as the "Pillar-and-Claw" is still on sale in enormous numbers in the windows of many opticians' shops. This stand consists of a brass folding tripod, a few inches high, supporting a brass pillar on which turns an outer tube (also of brass) with a compass joint at the upper end, to which the telescope is attached by two screws. This stand is a survival from the early days of last century, and may be dismissed at once as thoroughly inefficient. If the compass joint is made to work easily enough to allow of the delicate movements necessary for the following of an object, the telescope, not being balanced, will not remain where it is put; if the joint is screwed up so that the telescope is held steady by friction, then the motion is far too stiff to allow of the proper following of an object with even a low power. To compensate for want of balance, a rackwork slow motion in altitude is often fitted, between the pillar and the eyepiece end of the tube. This is usually far too quick in action, and, if it works loose, is worse than useless; and the application of the hand to the milled head by which it is actuated at once sets the whole instrument in vibration. A slow motion in Azimuth is sometimes (though comparatively rarely) fitted, consisting of an endless screw gearing with a far too small worm-wheel at the bottom of the pillar: this usually, after a little use, develops considerable "backlash." The "pillar-and-claw" stand is apparently intended to be used on a table at an open window (a most unsuitable place for observation), in which case it is hopelessly unsteady; and it is almost impossible to direct the telescope to an object anywhere near the zenith. These stands are usually beautifully finished, and form, no doubt, elegant ornaments for the library of the *dilettante*; for practical astronomical work they are useless.



By courtesy of [*Mr. G. Calver.*

EQUATORIAL REFLECTOR ON IRON PILLAR, WITH SLOW MOTIONS IN HOUR ANGLE AND DECLINATION.

This gives a very clear view of the various parts of the mounting and telescope.

The simplest form of stand for refractors that can be recommended for practical observing consists of a strong wooden tripod, supporting a short vertical axis, on which the telescope is carefully balanced on trunnions; the tripod is usually made to close up for portability, and should be of sufficient height to enable the eyepiece to be comfortably reached when the telescope is pointed nearly to the zenith. A tripod to carry a four-inch refractor may conveniently be not less than five and a half feet high to the trunnions, and six feet is usually better; the legs of the tripod should be connected, about half-way down, by means of three strong bars meeting in a joint immediately under the vertical axis. To provide for slow motion in altitude, the vertical axis is sometimes prolonged downwards as far as the joint just mentioned, and connected by a rackwork arm (similar to that on the " pillar-and claw ") to the eye-end of the tube. This has the disadvantage, as before, of causing vibration, and, in addition, the arm will, in certain positions of the telescope, come in the way of the legs of the tripod, in which case the slow motion is useless. And here it may at once be said that all slow-motion handles should be kept well away from the tube, if vibration is to be avoided. With large and heavy instruments the slow motions are brought to the eye-end with advantage, but for small, light instruments, any slow-motion handle connected to the tube is a fruitful cause of vibration.

For reflectors, the Altazimuth stand follows much the same lines as for refractors, except that since the eyepiece is now at the top of the tube, the tripod itself is much shorter, and the slow motions are modified as required. The tube of a reflector is usually a much heavier affair than that of a small refractor, and hence rather less liable to vibration; consequently the slow motion in altitude often fitted takes the form of a rod jointed to the upper end of the tube, and sliding in a socket attached to the stand, in which it may be clamped by a screw. Slow motion is obtained by means of a screw working in a nut at the upper end of this rod. This, if well designed, does not produce appreciable vibration. The slow motion in azimuth is obtained, as in the refractor, by means of a screw worked by a long handle attached to the screw by a Hooke's joint. But the varieties of arrangement that are to be found in the stands of reflectors are almost endless; this is, no doubt, because the construction of a reflector of even considerable aperture is well within the capacity of the amateur, if he possess some little manual skill and considerable patience; and every amateur constructor of a reflector has his own ideas as to how it should be mounted, so that all sorts of " make-shifts," some of them very efficient, are to be met with.

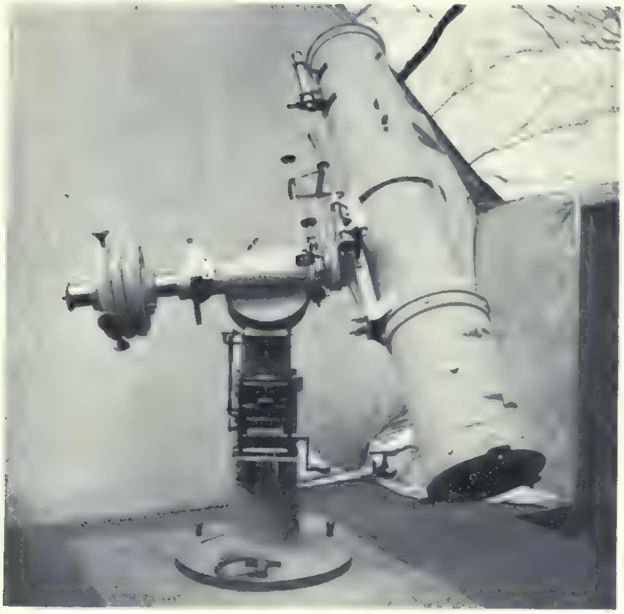
By courtesy of *Mr. G. Calver.*

TEN-INCH EQUATORIAL REFLECTOR, WITH SLOW MOTIONS.

Several refinements are here introduced, and the slow motions are brought to the eyepiece. The door in the tube through which the cover for the speculum is introduced is shown at the lower end of the tube, as well as one of the three screws by which the cell of the speculum is attached to the tube and adjusted to be at right angles with the axis.

A door is usually fitted to the tube of a reflector through which the cover of the speculum is introduced or removed; this should be underneath the tube, not above it (as usually fitted). Anyone who has to replace the cover in a shower of rain will appreciate this point.

The equatorial system of mounting a telescope, which is always used for the instruments in large observatories, has been made in various forms, but all of them have for their guiding principle the



By courtesy of [*Mr. G. Calver.*

TEN-INCH REFLECTOR ON EQUATORIAL MOUNT WITH DRIVING CLOCK.

A very complete and efficient instrument. The tube can be rotated in the cradle in which it is carried, so as to bring the eyepiece into the most convenient position, whatever the position of the object in the sky. The driving clock is seen in front of the pillar, and the slow motions are brought conveniently to the hand.

employment of two axes at right angles, one of which is parallel to the Earth's axis, as already explained. There are two main types employed ; the most obvious, but not that most used at the present day, is known as the English form ; in this form the polar axis is long, and is supported by two independent bearings at its ends, it usually takes the form of a rectangular frame with pivots at each end resting in the bearings, the telescope being balanced on trunnions at the sides of the frame, so as to swing in declination, the line joining these trunnions constituting the declination axis. Notable examples of this form are the 28-inch refractor at Greenwich (page 315), and the great 100-inch reflector at Mount Wilson (the largest telescope in the world) (page 39). The English form, when well designed, is steady and convenient, but it is somewhat difficult to arrange it so that the telescope may be easily directed to objects near the pole, and the two piers required to carry the bearing of the polar axis take up a good deal of room. For these reasons this mounting in its original form is not much employed at the present time. The so-called " German " form of mounting, however, has practically superseded all others, and almost every telescope of large size is at the present day mounted in this manner. In this form—first employed by Fraunhofer for the celebrated Dorpat refractor, of aperture nine and a half inches, with which Struve's great work on the measurement of double stars was carried out—the polar axis is short, and carried on a single tall pillar ; its upper end projects, and across it is fixed the declination axis, which carries the telescope at one end and a counterpoise weight at the other ; the polar axis can be adjusted in altitude and azimuth by means of appropriate screws.

The advantages of this form of mounting are very great. In the first place, only one support for the polar axis is required ; the space required is much less than in the English form ; the telescope can be directed without difficulty to any part of the sky ; and the eyepiece is always easily accessible, without any part of the stand coming in the way of the observer.

Notable examples of the German form of mounting are to be found in all the great observatories : the Yerkes 40-inch (page 41) and the Lick 36-inch (page 523), both refractors, are perhaps the best known.

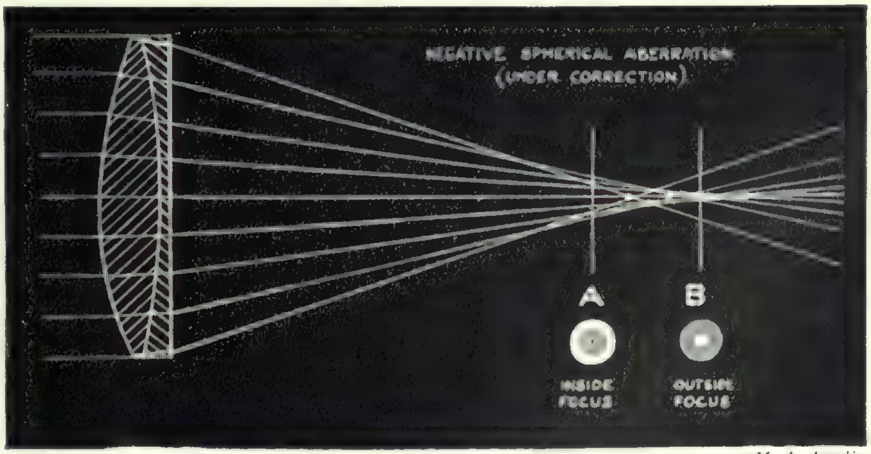
For the comparatively moderate apertures used by amateurs probably nothing will be found to surpass the German form. This may, in the case of small refractors, be easily carried on a portable tripod instead of a pillar ; but if a tripod is employed, the adjustments of the polar axis cannot, as a rule, be made very stable, and one of the advantages of the equatorial stand—the possibility of finding an object by means of the divided circles—is to a great extent lost. The main advantage of the equatorial, however—the following of the object by one motion only—remains ; for this purpose the adjustment of the polar axis need not be particularly accurate.

If any form of equatorial mounting is employed for a reflector, the position of the eyepiece—projecting from the upper end of the tube at right angles—introduces complications ; for unless care

is taken in the design of the stand, the eyepiece will on occasion be found to take up very inconvenient positions. In most equatorial stands for reflectors made at the present time, the whole tube is carried in a cradle attached to the declination axis, so as to be free to rotate about its own axis ; in this way it is possible to bring the eyepiece to any desired position. In larger instruments, say of eighteen or twenty inches aperture or more, the eyepiece and flat mirror are mounted on a cylinder which can be rotated on the upper end of the main tube ; either of these devices—especially the latter—is very liable to destroy the adjustments of the optical parts of the instrument, and the adjustment of the optical axis of the telescope with respect to the declination axis ; hence the finding of an object by means of the circles is never so precise with a reflector as with a refractor. If the position of the eyepiece is carefully thought out, it is possible to dispense with the rotating tube to a great extent, especially for the observation of Moon and planets ; but it must be admitted that it is a great convenience.

The above remarks apply, of course, to the Newtonian form of reflector, which at the present time is that almost universally employed; reflectors of the Cassegrain and Gregorian forms, in which the eyepiece is at the lower end of the tube (as in a refractor) and the light reaches it through a hole in the large speculum, are, as far as their mounting is concerned, on a par with refractors. The Gregorian form was in the Eighteenth Century, and for some time after, largely employed, opticians being very successful with it ; but it went out of use shortly after the coming of the achromatic refractor and the great development of the Newtonian telescope in the hands of Herschel. The Cassegrain form, in which the small concave mirror of the Gregorian is replaced by a convex, is much used at the present time for spectroscopic and other work with the largest reflectors, which are usually provided with several interchangeable mirrors for the purpose. With this form the effective focal length of the telescope can be made almost indefinitely great, and that in a small compass ; and now that exact methods of "figuring" the mirrors are known, which were not in the possession of the older opticians, who obtained their results almost entirely by "rule-of-thumb," it seems to the present writer that the Cassegrain form would well repay serious attention on the part of amateur constructors. As it is, the writer knows of no Cassegrain reflector of moderate aperture—say 8 or 10 inches—in regular use.

The amateur of limited means, to whom the purchase of an equatorial stand is a serious matter, will find that by a little ingenuity he will be able to mount his reflector fairly conveniently by the adoption of a form of the English stand which has been sometimes called the "Parallactic Ladder"—not that there is much of the ladder about it. If a strong rectangular wooden frame is made, rather longer than the tube of the telescope, and wide enough to allow it to swing through, the tube may be carried on pivots on the sides of the frame, care being taken that it is properly balanced; the frame itself forms the polar axis, and is carried on pivots at its ends. The lower end is supported on a block resting on the ground, with some



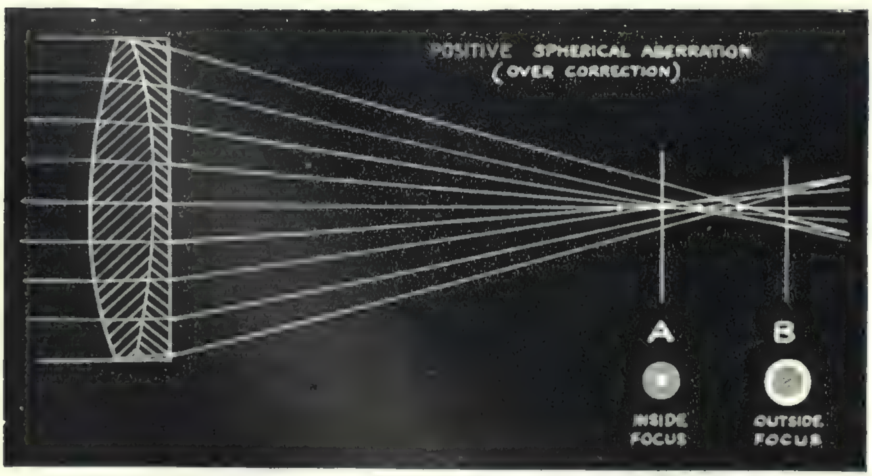
M. A. Ainslie.

NEGATIVE SPHERICAL ABERRATION (UNDER CORRECTION).

An object-glass or speculum having this error brings the marginal rays to a shorter focus than the central. If a screen is held within the focus, the disc of light on it will be brighter at the margin than at the centre ; conversely the opposite effect—a bright centre and darker margin—is produced if the screen is outside the focus. This effect is seen in the eyepiece when it is moved from the exact focus towards or away from the object-glass. An error of this kind is inherent in lenses and mirrors with spherical surfaces—hence its name.

simple form of bearing ; if nothing better is provided, a hole large enough to take the lower pivot may be made in a block of hard wood, cut to the proper angle, and prevented by two or more spikes from shifting its position on the ground, while the upper pivot of the frame is carried by two strong struts, long enough to clear the telescope in any position of the latter, and pointed at their lower ends so as to take a firm hold of the ground. The necessary adjustment of the altitude and azimuth of the polar axis may be obtained by shifting these struts until an approximate adjustment is obtained, which may be done quite accurately enough for following an object with one motion only. Slow motions, in this primitive form of mounting, are rather difficult to arrange for ; but the telescope may be steadied in declination by a " stretcher " similar to that often found on windows ; a rod sliding in a socket and fixed by a clamping screw. If the telescope is really well balanced, this will be found a very effective mounting, though perhaps rather lacking in steadiness in a strong wind. The same form of mounting might be used for small refractors, for which, indeed, it was originally suggested ; but in that case the frame will have to be much longer, and it will not be easy to make it sufficiently stiff to avoid vibration.

It has already been said that one of the advantages of the equatorial form of stand is that if it is properly adjusted so that the polar axis is accurately parallel to the axis of the Earth, and if the stand is further provided with circles indicating declination and hour angle (or Right Ascension), it is possible to direct the telescope with certainty to any desired object, whether visible or not to the unaided eye, and this in daytime as well as at night. But it must be added that the condition just stated—of proper adjustment of the polar axis—is, for this purpose, of very great importance. Detailed instructions for the adjustment of an equatorial stand would take up too much space, and these can as a rule be obtained from the maker of the telescope : and stands vary in their arrangements to such an extent that general rules are of little use. But if it is merely required of the stand that it shall be possible to follow an object in its diurnal course by one motion only, no very great accuracy is required. For the purpose mentioned, it is not necessary to employ divided circles, as it is generally possible to find an object by the help of a good star-map. All that is really required is that the polar axis shall be reasonably close to its proper position—that it shall point somewhere near to the pole—and for practical purposes, especially with small telescopes, it is sufficient (in the northern hemisphere) to point the polar axis as nearly as possible to the Pole Star—though this advice will not be of much assistance to observers south of the Equator. It may be objected that the Pole Star is not exactly at the Pole : but it is only about one and a quarter degrees from it, and it will be found that with the polar axis directed to the Pole Star it will be possible to follow an object for a considerable time with the



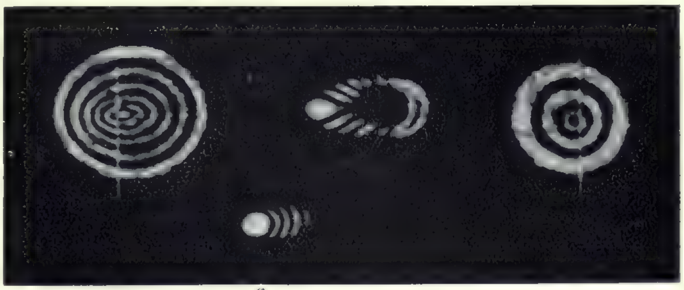
M. A. Ainslie.

POSITIVE SPHERICAL ABERRATION (OVER CORRECTION).

This is the opposite error to that shown in the last figure, and the effects on a screen within and beyond the focus are reversed. Spherical aberration in the case of object-glasses is corrected by the combination of two lenses of different glasses combined with suitable calculations of their curvatures. In the case of specula, the surface is made parabolic instead of spherical. If, in the case of an object-glass, the calculations are incorrect—or in the case of a speculum, if the surface is rendered hyperbolic—the correction is carried too far, with the result shown.

slow motion in hour angle only: and if the object gets too far from the centre of the field, a touch of the slow motion in declination will set matters right.

Failing the Pole Star—which, even in the northern hemisphere, may, owing to local limitations not be visible from the position of the observer—the polar axis can first be set reasonably correct in azimuth by the help of a compass (allowance being, of course, made for the magnetic "declination," or "variation," by which the needle deviates from the true meridian), and its altitude can then be adjusted to equal the latitude of the place of observation with the help of a piece of card cut to the proper angle, and a spirit-level or plumb-line. On some stands a scale is provided showing the altitude of the polar axis, with spirit-levels for its adjustment: but these are not really a necessity for ordinary purposes.



From "Telescope Objectives."] [*By kind permission of Messrs. Cooke, Troughton & Simms.*

EXTRA-FOCAL IMAGES (I).

A—Eccentric appearance of interference rings, due to the object-glass being out of adjustment. B—The focussed image of a star under the same conditions. C—Focussed image, when the mal-adjustment is not great. D—Image close to focus, moderate mal-adjustment.

It will be found, as a rule, that it is easier to set the polar axis at the correct altitude than to set it in the meridian: the following simple rule may be of service, it being assumed that the altitude of the polar axis is approximately correct.

Select a star and bring it into the centre of the field of view of a moderately high-powered eyepiece. If the polar axis is not in the meridian, it will be necessary to move the slow motion in declination (in addition to that in hour angle) from time to time to keep it in the centre of the field. Note in which direction the correction in declination has to be made, whether in the same name as the latitude—*i.e.*, to the north in the northern hemisphere, and to the south in the southern hemisphere—or in the reverse direction. Then,

> If the correction in declination is of the *same* name as the latitude, the upper end of the polar axis is pointing too far to the *Westward*;
>
> If of *opposite* name, it points too far to the *Eastward*;

and the polar axis may be shifted in azimuth in the direction indicated, and a fresh trial made; one or two such trials will generally serve to put the polar axis in sufficiently close adjustment for most practical purposes. In each trial, two or three stars in widely separated parts of the sky should be employed; the Moon, on account of its motion in declination, which is often rapid, should not be used in this test.

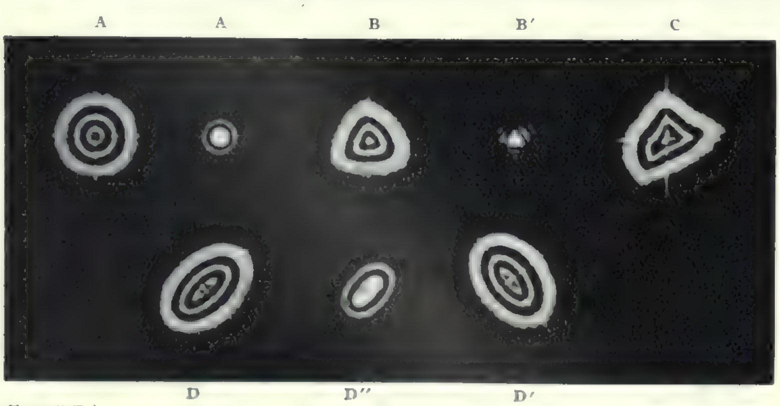
The tube of a telescope, both as to material and design, deserves some consideration. Small refractors, up to 4 or 5 inches aperture, are usually provided with brass tubes, and at the present time it seems to be the idea of most makers of such telescopes that they are intended to be looked *at* rather than looked *through*; lacquered brass looks very nice, but it is by no means the best thing from a practical point of view; zinc or iron, well painted, are much to be preferred. Large refractors almost always have tubes of painted sheet iron, and it is difficult to see why small ones should not also. The tubes of reflectors are usually of sheet iron, and if they are to be used under cover, this material is probably the best, so long as it is well protected from rust; but for a reflector to be used in the open air, as is the case with a very large proportion of amateurs' instruments, a wooden tube is much to be preferred, since the comparatively poor thermal conductivity of wood tends to keep the air in the interior of the tube at an even temperature, and the internal air-currents, which are sometimes very troublesome with an iron tube, are thus minimised. The amateur constructor of a reflector will also find that a *square* wooden tube, besides being easy to make, affords great facility for the attachment of any

additional apparatus that may be desired. A wooden tube, however, to be efficient, must be well made, of good material, and not liable to become distorted by heat or moisture ; its sides should not be less than five-eighths of an inch thick, and the corners should be bound with iron or strengthened in some way ; the inside measurement should not be less than an inch greater than the diameter of the mirror, so as to keep any air-currents—which appear usually to keep close to the sides of the tube—from interfering with the rays of light as they pass down and up the tube. The present writer has almost always found a 9-inch reflector in a wooden tube give steadier images than an 8½-inch in an iron tube, the two telescopes being both used in the open, and under identical conditions. It must be admitted, however, that the adjustments of the mirrors are not quite so permanent in the wooden tube as in the iron, and a square tube obviously does not readily admit of being mounted so as to rotate about its axis in order to bring the eyepiece to a convenient position.

Another advantage of the wooden tube for a reflector should not be overlooked : in such a tube it is very seldom that the flat becomes dewed, whereas in an iron tube, if used in the open air, there is frequent trouble from this cause. The writer had for some years a 9-inch reflector in a wooden tube, standing side by side, in the open air, with an 8½-inch in an iron tube; the flat of the latter constantly gave trouble by dewing over, that of the former, hardly ever. In any case the flat mirror should be mounted well within the tube : not less than eight or ten inches from its upper end.

The reader will no doubt have gathered from what has been already said that for the purposes of astronomical observation—at any rate, with anything in the nature of high powers—the quality of the telescope is all-important ; and this depends chiefly on the quality of the object-glass, or mirror, though it must not be thought that the eyepiece is in this respect of no importance. But it is fairly obvious that unless the image formed by object-glass or mirror is clean and sharply defined, no excellence in the eyepiece will make it so, nor will a clear view of the object be obtained. It is therefore as well to consider one or two simple tests by which the observer may satisfy himself as to the quality of his instrument, and there are no better tests for the quality of a telescope than those recommended by Mr. H. Dennis Taylor in his book, "Telescope Objectives" (published by Messrs. Cooke, Troughton & Simms) which will be found of the greatest interest and assistance to the observer. The following directions are largely based on this work.

If the object-glass (and in what follows the term "object-glass" may be taken to include mirrors) is really good, all rays of light proceeding from any point of the object will be brought together at the focus to form a minute disc—generally known as the "spurious disc"—which in the case of the average refractor should be rather less than a thousandth of an inch in diameter, and in the case of a reflector, which, as a rule, has a much shorter focal length compared to its aperture, not more than 1/1600 or 1/2000, or even smaller. If the telescope is directed to a moderately bright star—say of the fourth magnitude—and the atmosphere is steady and free from cross-currents, this disc should be plainly seen with a power of about thirty or forty to the inch of aperture ; and it should come in and out of focus with a very slight movement of the eyepiece. Bright stars will show a somewhat



From "Telescope Objectives." [*By kind permission of Messrs. Cooke, Troughton & Simms.*

EXTRA-FOCAL IMAGES (II).

A, B, C, D, and D′ are out-of-focus sections of the cone of rays, seen when the object-glass is "squared on," but irrespective of other faults. A′, B′, and D″ show the focussed images corresponding to A, B, and D. D, D′, and D″, are also examples of astigmatism.

larger disc and faint stars a smaller. On a really first class night, this image should be accurately circular, and free from " wings " and other stray light, except that at least one thin " diffraction ring " should be seen around the disc accurately circular, and concentric with it. In the case of bright stars, more than one ring may often be seen, while faint stars usually show no conspicuous ring at all, it being too faint to be detected, although present.

An object-glass, to perform properly, must be set accurately at right angles to the axis of the tube—which is usually expressed by saying that it must be " squared on." If the glass is not properly squared on, the light from the star enters it obliquely, and the image is deformed from the concentric " disc-and-ring " that it should be to an irregular image with a " tail " at one side; this is more evident when the image is just out of focus. To effect this adjustment, screws are provided in all first-class instruments by which the cell of the object-glass can be slightly tilted in any direction; these screws are often omitted in low-priced instruments, but are essential if good results are to be obtained. It will be found that an instrument known as " Cheshire's squaring-on eyepiece " is a great help in making this adjustment. If the disc is not circular, the object-glass (or, very improbably, the eyepiece) suffers from what is known as " astigmatism," in which case careful movement of the eyepiece in and out will show that in two positions the " disc " will take the form of a very short line. These lines (called the " focal lines ") will be at right angles to one another. It must be remembered, however, that the same appearance will be produced by the small mirror in a Newtonian reflector, if it is not, as it should be, perfectly flat ; and that the eye itself suffers from this defect much more often than is commonly supposed. To locate the cause of the trouble, first of all the eyepiece may be rotated in its tube ; if, as is improbable, the fault lies in the eyepiece, the direction of either line will change as it is rotated. Then the observer should try moving his head so that his eye rotates with respect to the eyepiece, when any astigmatism in the eye will be at once apparent by the movement of the focal line—and this latter test is much more sensitive with a low powered eyepiece, on account of the greater diameter of the beam of light emerging from it. If the eye and eyepiece are certainly not at fault, the defect is due to the object-glass in the case of a refractor, or to one of the mirrors in a reflector. To test this latter point, the mirror will have to be rotated in its " cell " (the metal ring in which it is mounted) ; if the focal line remains in the same direction, the " flat " is at fault, if it moves, the large mirror (or " speculum ") is convicted. The defect may be due to careless mounting. Mirrors and object-glasses should never be mounted tightly in their cells, but should have a *very* slight " shake," only just perceptible : the slightest strain will affect the performance of an object-glass and ruin that of a mirror. In reflectors, the flat mirror is often at fault in this way : a " pinched flat " is a very common cause of failure in definition.

If the defect of astigmatism is exhibited by flat mirror or eyepiece, it can be cured at a comparatively small expense, by substituting good ones for bad; but if it is due to object-glass or speculum, there is no cure. A telescope thus affected may perform passably with low powers, but it will never

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EXTRA-FOCAL IMAGES. (III).

Sections close to the focus, showing astigmatism. A within the focus, and B beyond it (or vice versa).

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EXTRA-FOCAL IMAGES (IV).

Spherical aberration : A, within the focus ; and B, beyond it. The interference rings grow fainter towards the centre in A, showing positive spherical aberration—marginal rays focussing farther from the objective than the central. For negative spherical aberration (focus shortest for marginal rays) the figures should be reversed.

A  B

From "Telescope Objectives."
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EXTRA-FOCAL IMAGES (V).

Slight residual spherical aberration: Sections close to focus, central rings weak. A, within; B, beyond, the focus.

A  B

From "Telescope Objectives."
[By kind permission of Messrs. Cooke, Troughton & Simms.

EXTRA-FOCAL IMAGES (VI).

A—"Spurious disc," or image of a star given by a perfect objective under very high magnifying power. B—The focussed image sometimes given by a large object-glass when resting on three points without intermediate supports to counteract the flexure due to the weight of the glass.

exhibit close double stars, or the finer details of Moon and planets, as they ought to be seen, and it will prove a constant source of disappointment to the observer, and should be at once rejected.

Starting from the position of exact focus, as the eyepiece is moved inwards or outwards, the "disc-and-ring" will be seen to expand into a patch of light, which should be perfectly circular, and should have a fairly sharp margin and be nearly uniform in brightness over its entire area. If this patch of light is irregular in outline, or shows strong differences in brightness at different points, the object-glass is of bad material or badly worked. Inequalities of refractive power, or "striae," and lines of unequal density are probably present, though with the optical glass obtainable at the present day this will not often be the case to any serious extent, especially in small sizes. The specula of reflectors suffer less from this cause, since the light does not pass through them, although any want of perfect annealing of the glass of which they are made, or any irregularities of temperature during the "figuring" process, will inevitably have a bad effect on their performance.

Further, the patch of light should be equally bright and uniform whichever way the eyepiece is moved from the exact focus; if it is not—if there is an obvious difference in the appearance within and beyond the focus—the object-glass suffers from what is generally known as "spherical aberration," and does not bring the central and marginal rays to the same point. If the patch of light within the focus has a fairly sharp edge, but much more light in the margin than at the centre, while beyond the focus the edge is misty and ill-defined, the great preponderance of light being in the centre; then the marginal rays are brought to a focus nearer to the object-glass than the central, and the object-glass is said to be "under corrected": if the appearances are reversed, it is "over-corrected," the marginal focus being now the longer. Obviously an object-glass suffering from this defect cannot be expected to give a perfect image of a star, and this "spherical aberration," if pronounced, will make it impossible to get a really sharp image of any object whatever; this is especially the case with reflectors, on account of their comparatively short focus, which greatly accentuates the want of definition due to this defect. When testing a reflector for this defect, it should be noted that owing to the presence of the small mirror in the centre of the beam of light incident on the mirror, the out-of-focus disc will show a central dark patch—this should be the same, or nearly so, whichever side of the focus is taken. In fact, if we neglect colour, a good object-glass or mirror, when the image is put out of focus, should give no indication as to whether the patch of light seen is within the focus or beyond it.

In making the above test, a fairly high power eyepiece should be employed: say, 30 or 40 to the inch of aperture. Most eyepieces have some spherical aberration of their own, which is greater in the case of low powers. For this reason an object-glass or speculum (especially the latter) which appears perfect with a moderately high power will usually exhibit a certain amount of under-correction with low powers. For the observation of objects for which low powers are required this is of no great importance; but the correction should be as perfect as possible with high powers.

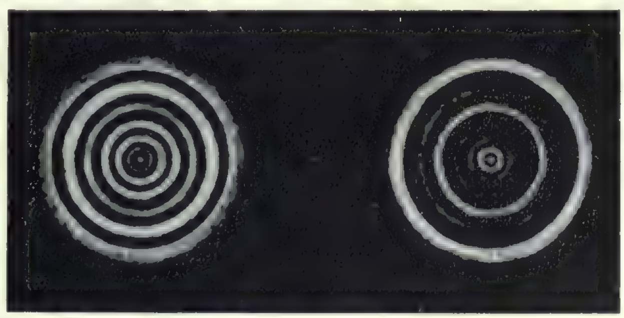
If the object-glass successfully passes this test, a still more searching one may be applied. If the out-of-focus patch of light is carefully examined, it will be seen to consist of a central point of light with a series of extremely delicate rings surrounding it, the outermost ring being somewhat thicker

and brighter than the rest. These rings, like the ring or rings seen under good conditions around the spurious disc in focus, are due to diffraction, or the mutual interference between the light-waves from the various parts of the aperture of the object-glass on their way to the focus. They afford a test of extraordinary delicacy as to the perfection of the " spherical correction," and will indeed reveal defects which would be overlooked in any other method. They are not, however, very easy to see just at first, and the eye requires a certain amount of " education " in order to see them easily and grasp their significance.

With most refractors it is best to commence by racking the eyepiece some way *within* the focus, and the rings are usually more easily seen through a piece of apple-green glass, which will remove any effects due to the outstanding " secondary spectrum " to be described later. If the spherical correction of the object-glass is perfect, these rings will appear just the same within and beyond the focus. If they are more easily seen within the focus, the glass is under-corrected ; if more easily beyond the focus, over-corrected. Slight errors in correction may in this way be rendered evident which would escape notice in the method earlier described.

Further, by careful observation of these diffraction rings in the " extra-focal image," what is known as " zonal aberration " may be detected. An object-glass may, as a whole, give a very approximately accurate concentration of the rays of light to one point ; but it is seldom, especially in large glasses, that certain " zones " of the aperture are not to be found which have a very slightly longer or shorter focal length than the rest. If this defect is quite slight, the effect on the image is not serious, and many first-class object-glasses will be found to suffer slightly in this way ; but for *perfect* performance every part of the object-glass must perform its work accurately, and for critical work with high powers there is no doubt that perfect " zonal " correction greatly assists the formation of a perfect image.

If the " extra-focal image " is examined with a fairly high power—say about 40 to the inch of aperture—any zonal aberration will make itself evident by a strengthening of one or more of the rings. For example, if within the focus we find that a ring about half-way between the centre and margin of the system is brighter than the rest, the indication is that there is a zone of the object-glass about half-way between the centre and the margin, which brings the rays to a rather shorter focus than the rest of the lens ; and in the " extra-focal image " beyond the focus this zone will be manifest by a deficiency in the brightness of the corresponding ring. If the appearances are reversed—*i.e.*, if beyond the focus one of the rings is brighter than the rest—the indication is that the corresponding portion of the object-glass has a focal length somewhat longer than the rest. This test is extremely delicate, and comparatively few object-glasses—even first-class ones—will be found which do not give *some* indication of such " zones." At the same time this effect ought not to be

A  B

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EXTRA-FOCAL IMAGES (VII).

An example of marked Zonal aberration. A zone of the object-glass about half-way out has a longer focus than the rest, and between this and the margin there is a marked zone of short focus. (A within, B beyond, focus).

A  B

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EXTRA-FOCAL IMAGES (VIII).

Another example of Zonal aberration. The margin and centre of the object-glass have a longer focus than the rest. (A within, B beyond.)

obtrusive. An object-glass badly affected with this fault will—especially beyond the focus—show an extra focal image in which almost all the light is concentrated into one or two bright and widely-spaced rings ; such a lens will never give what may be called critical definition.

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EXTRA-FOCAL IMAGES (IX).

The general figure of the object-glass is pretty good, but a small region in the centre has a longer focus than the rest. (A within focus, B beyond.)

So far we have only considered faults in the object-glass of the nature of spherical or zonal aberration, without considering the question of colour. If an object-glass of the ordinary type consisting of two lenses were perfectly "achromatic," it would bring all the different colours of the spectrum to the same focus, and no image seen with such a glass would show any outstanding colour. This is, of course, the case with a reflecting telescope, since the action of a mirror, however imperfect otherwise, is quite independent of the wave-length (*i.e.*, the colour) of the light falling on it ; reflectors are therefore perfectly achromatic, a fact which constitutes one of their greatest advantages. It happens, however, that as yet no object-glass of the usual construction, with a convex lens of crown glass and a concave of flint, has been produced which does not exhibit a certain amount—often, especially in large sizes, a great deal—of colour around the images of bright objects, due to outstanding light which cannot be made to come to the same focus as the rest. This (at present) unavoidable defect is known as "secondary spectrum." With object-glasses of the common form, and with the optical glass at present available for their construction, it is not possible to combine more than two colours of the spectrum to the same focus ; and these colours are usually chosen by the computer, so that light of the brightest portion of the spectrum—roughly that lying between yellow and green—is as far as possible concentrated at the focus, the light of the rest of the spectrum being perforce left to go its own way, and the result is that with the ordinary object-glass the bright rays come to a focus nearer to the object-glass than any others. It thus happens that the other rays which have to be left out of the account combine with one another to form coloured fringes round the images formed by the brightest rays, and in the case of the image of an extended object—such as the disc of Jupiter—these "vagabond colours" are apt to dilute and modify, to a great extent, the natural colours of the object : an explanation of the great superiority of the reflector in colour-observations.

From "Telescope Objectives."
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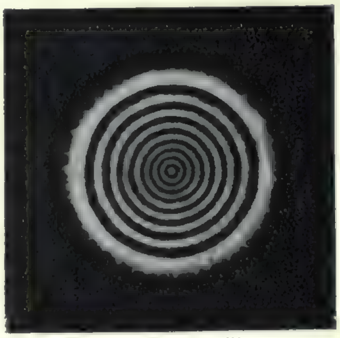
EXTRA-FOCAL IMAGES (X).

Sections of the cone of rays given by a perfect object-glass, taken very near the focus and on opposite sides of it, and viewed with a very high magnifying power.

These coloured fringes around the images of bright objects in focus are usually of a bluish hue. If the image of a star of average colour is examined—and the Pole Star is excellent for this purpose—the image within the focus will present a reddish border, and outside the focus the border may be greenish. But it may at once be said that what constitutes "good colour correction" is to a very great extent a matter of individual taste, and that neither observers nor opticians are agreed upon this point. And it is also to be



From "Telescope Objectives."]
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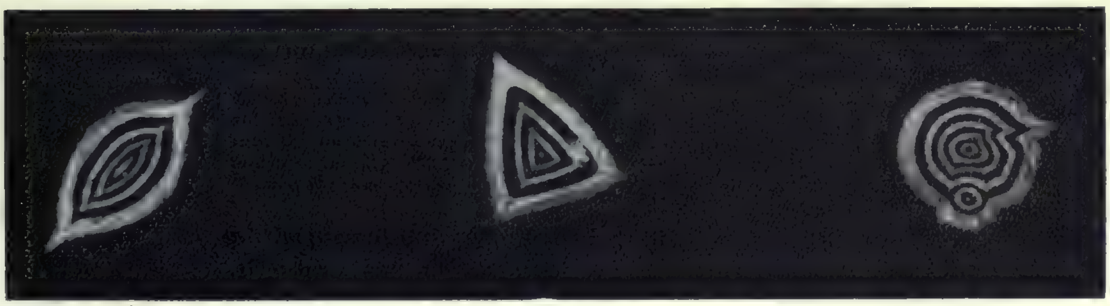
EXTRA-FOCAL IMAGES (XI).

A section of the cone of rays from a perfect object-glass, about a quarter of an inch from focus, with moderate power.

remarked that the colour correction of a given object-glass will vary very perceptibly, not only with the colour of the star on which it is tested, but also with the power of the eyepiece employed, and the type of that eyepiece. The Huyghenian eyepiece is that most usually employed, and with such it may be said that if the colour correction appears satisfactory with an eyepiece giving a magnifying power of 40 times the aperture in inches, it will appear, with a very low power, noticeably inclined to "under-correction," *i.e.*, to a certain amount of outstanding *red*. All that can really be said is that with the eyepiece that is to be most commonly used—and this will, of course, depend on the class of observation contemplated—the unavoidable outstanding colour should not be so obtrusive as to affect seriously the accuracy of the results obtained. As a general guide, however, we may take the Pole Star. Its image in focus should present a colourless or perhaps yellowish white disc, with perhaps the faintest trace of blue round it ; within the focus, the expanded disc will be greenish white with a narrow reddish fringe ; just beyond the focus a red centre will be seen, and farther out this will turn into blue, while if there is any coloured fringe at the margin it should be greenish. But, as has just been said, no very hard and fast rules can be laid down.

It may here be mentioned that although it has not as yet been found possible to abolish the secondary spectrum completely in object-glasses of the usual construction, of two lenses, yet a great improvement can be made by the use of more than two, together with the use of glasses of the requisite optical qualities. The well-known "Photo-visual" object-glasses of Messrs. Cooke, Troughton & Simms are



A B C

From "*Telescope Objectives.*"] [*By kind permission of Messrs. Cooke, Troughton & Simms.*

EXTRA-FOCAL IMAGES (XII).

A and B—examples of the effect of violent mechanical strain, due to bad mounting or imperfect annealing. C—example of effect due to the presence of veins of unequal density in the material of the object-glass.

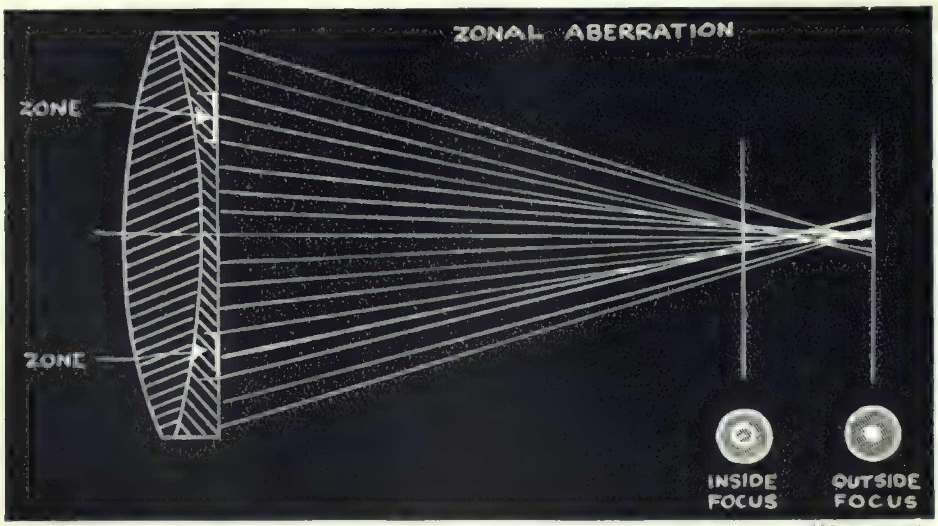
a case in point. In these object-glasses, it has been found possible, by the use of three lenses of specially selected Jena glass, to reduce the secondary spectrum to a negligible amount, so that the colour correction of these glasses is practically as perfect as that of a reflector. It must, however, be regretfully added that these object-glasses are of necessity extremely costly.

We may now turn to the consideration of the eyepiece of the telescope. In its essence this is merely a simple microscope of varying power applied to view and magnify the image formed by the object-glass or mirror, and it need not, in its simplest form, be more than a simple convex lens of the requisite power ; in fact, such simple lenses are recommended by some experienced observers as giving more light and better definition than any of the more complicated forms. But it will be found that a simple lens has the great disadvantage that it will only give a good image at, or very near to, the centre of the field of view ; and for low powers this renders it quite unsuitable for observations of extended objects, such as clusters and nebulæ, while with high powers the ever-present difficulty of following the object is very greatly accentuated.

These disadvantages were recognised by Huyghens early in the history of the telescope, and the eyepiece bearing his name has been in common use ever since his time. Indeed, probably ninety-nine out of every hundred eyepieces usually sold with small telescopes are of this form. If well made, and of proper design, this eyepiece will give, especially with refractors, good images over a comparatively

large field of view, and this with little exhibition of false colour. It is not, however, so well suited to reflectors, as it has considerable spherical aberration of its own, which, with the comparatively large ratio of aperture to focal length usual in a reflector, is apt to impair the definition with low powers. A somewhat flatter field is obtained with eyepieces of the Ramsden construction, though as commonly made they cause a good deal of false colour towards the margin of the field of view. This is obviated in some eyepieces—notably those employed with the well known "prism" binoculars—by making the lens nearest to the eye itself achromatic, or nearly so. When thus arranged, this eyepiece is probably the best of all for low and moderate powers. For higher powers, there are several kinds of eyepiece to be obtained which perform, especially with reflectors, notably better than the Huyghenian. These are usually rendered achromatic by the employment of two kinds of glass, somewhat in the manner of object-glasses: of these, the "Monocentrics" of Steinheil and Zeiss, the single lens eyepiece of Cooke, the Zeiss "Orthoscopic," and Browning's Achromatic eyepieces may be mentioned among many varieties. The present writer has found nothing better, either for refractors or reflectors, than the Zeiss "Monocentrics," which consist of a single achromatic combination of three lenses cemented together.

A table has already been given showing roughly the powers which will be found most useful for two specified apertures, but it must be admitted that eyepieces of good quality are somewhat expensive, and for general purposes it will usually be found that three will cover all the work commonly undertaken by the amateur. For a 4-inch refractor, probably 60, 100, and 140 will be found most useful; for an $8\frac{1}{2}$-inch reflector, 60, 150, and 250. Although on a good night higher powers than these will give a good image, it does not follow that more detail will of necessity be seen. A certain proportion of light in the image to magnifying power is always essential, and high powers, which spread the available light over a larger apparent area, often result in a general faintness of the image which renders it difficult to make out fine details, although they may be present in the image. Even in the resolution of close double stars into their components, for which it might be thought that very high powers would be an advantage, moderate powers usually suffice. Consider, for example, the case of a 9-inch reflector. By the formula already given, such an aperture, on a good night, ought to separate two stars whose apparent distance apart is about 0·55 second or so; that is to say, the two discs in the image will just be separated. Now, to see the star double we must magnify this image by means of the eyepiece sufficiently to allow of their being separately seen *by the eye*. A fairly keen eye will, unaided, separate two points of light (not too bright) if they are not less than about two minutes of arc apart. In order, then, to render visible the two components of the star of 0·55 second separation, we shall have to magnify it 120 seconds / 0·55 second, or 218 times; and this is quite a moderate power for a 9-inch aperture; in fact, not



[M. A. Ainslie.

ZONAL ABERRATION.

The zone of the object-glass indicated brings the rays to a somewhat shorter focus than the rest of the glass. The effect on the "out-of-focus" image as seen within and beyond the focus is shown by the small circles: these correspond to the positions indicated of a screen intercepting the light. The amount of aberration is very greatly exaggerated for clearness.

more than about 24 to the inch. Any higher power will do no more than render the separation somewhat more obvious. It will not result in the resolution of a closer double for the discs will overlap, no matter what power we apply by means of the eyepiece. The eyepiece can only magnify the image, and cannot modify it in any way, and if the image consists of two overlapping discs, no eyepiece can make it appear anything else.

At the same time, as has already been mentioned, it is often possible to detect the double nature of a star even if the discs are overlapping ; for this purpose, of course, a high power is of advantage, if the night is good enough, as giving a clearer view of the *shape* of the image.

[*M. A. Ainslie.*

ACTION OF ACHROMATIC OBJECT-GLASS.

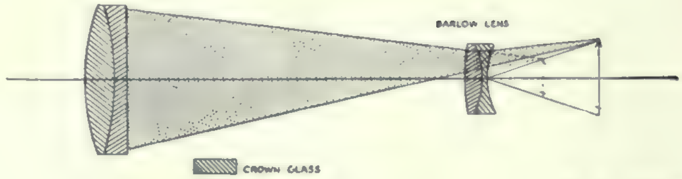
An achromatic object-glass brings the brightest rays of the spectrum (those between yellow and green) to the shortest focus, and the rest of the spectrum focusses at various points farther out. These latter colours combine to form the " secondary spectrum."

Although, as mentioned above, three eyepieces are sufficient to cover most work, it is very often a considerable advantage to be able to increase or diminish the power to suit special conditions of seeing, mist, etc. Fortunately, this can readily be done without the necessity of adding to the stock of eyepieces, by the use of the simple device known as the " Barlow " lens. This device—the advantages of which are by no means appreciated as they should be—consists of a concave achromatic lens, usually of (negative) focal length about 8 inches, which is mounted in a short piece of tube capable of sliding inside the " draw-tube " which carries the eyepiece. If such a lens, say of 8 inches focal length, is placed 4 inches within the focus of the object-glass, so as to receive the rays from the latter before they come to a focus, it will throw the image 4 inches farther out, and at the same time double its size : if the eyepiece is unchanged, of course the magnifying power is now doubled. If the Barlow lens is moved nearer to the focus of the object-glass, the image will not be thrown so far out, and the extra amplification will be less ; moving the Barlow lens farther within the focus of the object-glass has the contrary effect. It will be seen that in this way a very delicate adjustment of the magnifying power is obtained. The advantages gained by the use of the Barlow lens are considerable. In the first place, for a given magnifying power the eyepiece used need not be of anything like such short focal length as is normally the case, and in consequence the errors introduced by the eyepiece are much diminished, since—and readers acquainted with optics will appreciate this point—the diameter of the beam of light emerging from the eyepiece bears a smaller ratio to the diameter of the eyepiece lenses, and what has been described above as " spherical aberration " is greatly diminished. This advantage is especially felt in the case of reflecting telescopes, which are usually of short focus as compared with their apertures. By the use of the Barlow lens the *effective* focal length of the mirror or object-glass may be greatly increased, which is always an advantage with any form of telescope.

Against the advantage just mentioned must be set the slight loss of light caused by the extra lens—not, as a rule, of much importance—and a slight tendency to the formation of " ghosts," or " smudges " of light in the field of view caused by reflections at the surfaces of the lenses, but these drawbacks are not serious as compared with the great utility of the device.

The Barlow lens usually takes the form of a " concave meniscus," or " concavo-convex " : the convex side should always be *towards the object-glass.*

Eyepieces may either be screwed into the end of the draw-tube or they may be mounted in a short piece of tube which can be pushed into an "adapter": the latter method is very greatly to be preferred. By far the greater number of eyepieces sold at the present day, however, are made to screw in, the thread being what is supposed to be the "astronomical" thread, which should be, but often is not, a standard size. Eyepieces made to push in are changed much more rapidly, and are much less liable to get dropped and damaged in the dark, but opticians seem unable to agree upon a standard gauge of tube, even when they make their eyepieces to push in. Consequently, it is often impossible to use the eyepieces of one maker on the telescope of another; a fact much to be deplored. As a rule, the screw-in eyepiece supplied is a good example of unreasonable conservatism on the part of the makers. It usually is much heavier than it ought to be, and it usually seems to be the object of the maker to sink the lens nearest the eye as deeply as possible in the lump of brass in which it is mounted, whereas, especially in the case of high powers, it should be brought as close to the *eye* as possible. Again, makers of these eyepieces usually seem to imagine that provision must be made, even with the highest powers, for the attachment of a dark glass for viewing the Sun; whereas practical observers know very well that on the Sun, low powers only are generally used. The result is that the difficulty, with high power eyepieces, of getting the eye anywhere near the eye-lens, is increased by the flange to which the dark glass is supposed to screw. Altogether, the astronomical eyepieces generally made in this country are much behind the times. They may go very well with the "Pillar-and-Claw" stand, but are very unsatisfactory from the practical point of view.

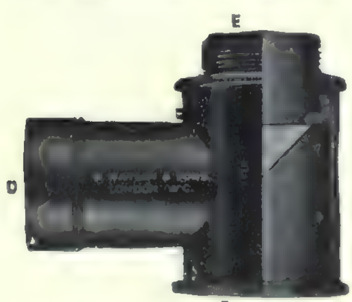


M. A. Ainslie.

ACTION OF BARLOW LENS.

The Barlow lens, which is an achromatic concave, or "negative," lens placed within the focus of the object-glass, bends the rays outwards and thus enlarges the image, at the same time throwing the latter farther from the object-glass.

From what has been said above, the reader has probably realised the undesirability of pushing magnifying power too far; but it is not, perhaps, as well recognised that it is possible to err in the other direction, even when the objects observed would appear from their nature to invite the use of the lowest possible powers. In all cases it must be remembered that the object is seen, apparently, against the background of the sky. Now, the brightness of this apparent background depends to a great extent upon the magnifying power in use. There is always, even on the darkest and clearest nights, *some* light in the sky, and the higher the magnifying power, the more this is diluted; the lower the power, the brighter the apparent background. Now, a little thought will show that when we wish to observe the faintest details, of, say, a diffuse nebula, we must have the contrast between the details we wish to observe and the background as strong as possible, and the observer will find that, as a rule, it is not the lowest power that gives the best contrast. As an example, we may take the Great Nebula in Orion, which is familiar to almost all observers. With a power of 40 on a 9-inch reflector, there is so much light in the background that the outlying details are lost; with a power of 100 on the same aperture, the contrast is greater owing to the darker background, and the details are more easily seen, though, of course, the extent of the field of view—*i.e.*, the amount of the nebula visible at one time—is much less. No hard and fast rule can be laid down, but as a rough average, unless the nature of the observation is such that the largest possible field of view is absolutely necessary, about 8 or 9 to the inch of aperture will be found the best power for such objects as clusters and extended nebulæ. For the detection



By courtesy of Messrs. W. Watson & Sons.

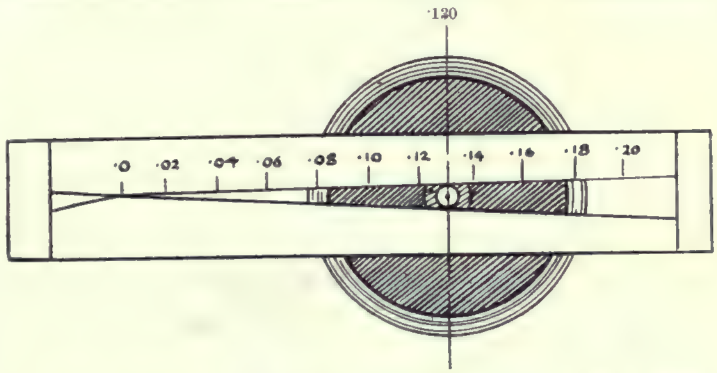
THE STAR DIAGONAL REFLECTOR.

A right angle prism fitted to the eye-end of the tube, reflecting the whole of the light from the object-glass from its inclined surface to the eyepiece at the side of the tube.

of faint companions to bright stars, the power may with advantage be considerably higher—perhaps about 15 or so to the inch, or even 20.

But there is another factor which limits the available power in the downward direction : the diameter of the pupil of the eye. For many years it has been assumed that in the dark the pupil of the eye expands to not more than one-fifth of an inch in aperture. Recent experiments by Dr. W. H. Steavenson, however, have shown that, with young eyes at least, the aperture of the pupil in darkness is considerably larger than this ; in fact, about one-third of an inch. (Whether this is the case with the eyes of persons of middle age, however, is perhaps open to question.)

Now it may be proved that the magnifying power of a telescope can be obtained by dividing the aperture of the object-glass by the diameter of the beam of light which leaves the eyepiece—this is, in fact, about the best way of determining it—and it follows from this that if the magnifying power is less than about three times the aperture in inches, the emergent beam will be more than one-third of an inch in diameter, and—according to Dr. Steavenson's result—it will therefore be greater in diameter than the pupil of the eye. This means that under these conditions the light from the margin of the object-glass will not enter the eye, and the telescope is really diminished in aperture, and, of course, in light-gathering power. Hence, if we wish to employ, for example, a power of 30 diameters, an aperture of 10 inches will transmit as much light to the eye as any larger aperture. Similarly, the lowest power that will admit of the useful employment of the whole of a 4-inch aperture is twelve. If, as the present writer believes to be the case, the pupils of eyes of middle-aged persons do not expand to more than one-fifth of an inch as an average, these figures will have to be modified : 6 inches for the power of 30, and power 20 for the 4-inch.



[*M. A. Ainslie*

MEASUREMENT OF MAGNIFYING POWER BY MEANS OF THE "DYNAMOMETER."

The "Dynamometer" is shown (full size) in position across the eyepiece. The central bright circle is the Ramsden disc, the margin of which just touches the sides of the V-shaped slot. The scale (which is more finely divided than is here shown) in the figure gives ·130 inch as the diameter of the Ramsden disc : with a five inch object glass or mirror this would indicate a magnifying power of 5/0·130, or 38·5 diameters.

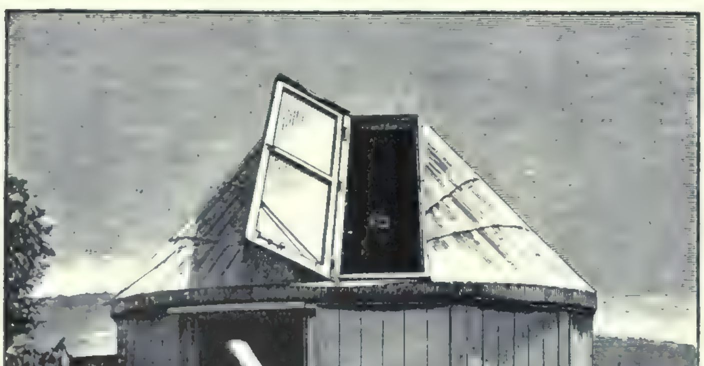
It was said just now that the magnifying power of a telescope may be found by dividing the diameter of the object-glass by that of the beam of light emerging from the eyepiece. If a telescope focussed for a distant object is directed to the sky or to any bright surface, and the eye removed a foot or two from the eyepiece, a small circular patch of light will be seen in rear of the eyepiece, and close to it. This is the image of the object-glass formed by the eyepiece, and is generally called the "Ramsden disc," after the celebrated optician of that name. All the light from a star passing through the object-glass must evidently also pass through this disc, and the diameter of the latter is therefore the diameter of the emergent beam. This diameter can be measured in various ways. Probably the most convenient is a little instrument first suggested by the late Rev. E. L. Berthon, and called (rather unfortunately) the "Dynamometer," or Power-measurer. In this, a graduated strip of metal has a V-shaped slot cut in it, the sides of the slot being perfectly straight. The edges of the Ramsden disc are made just to touch the sides of this slot, and the diameter is read off directly from the scale. A fairly efficient substitute may be made by fixing two strips of paper, inclined at a small angle, to a frame, and graduating the strips to show the width of the space between them at any point ; or, for low powers, a small pair of compasses (what are usually known as "spring bows") may be used. But with either of these methods the accurate measurement of high powers is difficult, on account of the very small diameter of the Ramsden disc. This will be realised when it is considered that with a power of 40 diameters

to the inch of aperture, the diameter of the Ramsden disc is only one-fortieth of an inch. If the exact value of a high magnifying power is required, it is best to get a reliable optician to make an accurate measurement of the "equivalent focal length" of the eyepiece; this, divided into the focal length of the object-glass, gives the magnifying power required.

Perhaps it may be as well to warn the reader that the expression "magnifying power," as applied to a telescope, always means the ratio of the *linear* apparent diameter of the object, as seen with the telescope, to the same as seen with the unaided eye. Sometimes a telescope is advertised as having a power of, say, "256 *superficial*." This simply means "16 linear," or "16 *diameters*," which is the correct expression. $(256 = (16)^2.)$

The observation of objects at a considerable altitude with a refractor is apt to be extremely tiring, unless the observer's head is supported in some way; failing this, a right-angle prism attached to the eye end of the tube, so as to throw the light out to an eyepiece at the side, is a great convenience, the loss of light by absorption in the glass being trifling. It has, however, the great disadvantage for lunar and planetary work that the image is reversed "right-and-left" (or "up-and-down," as the case may be) as in a looking glass. This renders the recognition of the features of these objects somewhat difficult.

Opinions may differ as to the best situation for the telescope, and this point is usually settled by considerations of space, view of the sky, and other local conditions, but there is no doubt as to the worst—an open window. The air in a room is almost always at a different temperature from that out-of-doors, and an open window always forms a meeting-place of currents of unequally heated air, which ruin the definition of the image. Again, any vibration caused by movement of persons and things in the house—or even of the observer himself—is enormously magnified by the telescope; and it is practically impossible to observe an object anywhere near to the zenith. If an open window is the only available place from which observations can be made, the object-glass should be pushed outside as far as possible, so as to mitigate in a small degree the effect of the air-currents just mentioned; but this is about all that can be done, and it is not, as a rule, very effective. It seems worth while to warn the beginner that no good performance can be expected of a telescope if it has to look through a plate-glass window: this is equivalent to adding another lens of very poor quality to the object-glass, and even the best plate-glass is far too irregular, as regards flatness and refractive power of the glass, to do otherwise than seriously impair the performance of the instrument. If observations have of necessity to be made from a window, *there must be no fire in the room,* and the window



From "Descriptive and Practical Astronomy," by G. F. Chambers.
By courtesy of the Clarendon Press.

A SMALL AMATEUR OBSERVATORY.

This is an excellent form of observatory for a refractor of moderate aperture. It houses a five-inch equatorial refractor and a small transit instrument for time-determination. The latter is shown at the small window in the distance. The revolving roof is of painted canvas on a wooden frame.

must be left wide open for as long as possible before observations are commenced.

The proper place is *out-of-doors.* A spot should be selected from which the best view of the southern and western sky can be obtained; the northern part of the sky is less important, so long as it is possible to see the Pole-star from the spot selected. If possible, the telescope should not stand on grass. A gravel or cinder surface is far better, and there will be less trouble from dewing and vibration. "Do not point the telescope above, or to leeward of, a chimney *in use,* unless you want to study the effect of a heated current of air." If the telescope is kept indoors and carried out to its stand each night, let it stand in the open, if possible, for half an hour before observations are commenced; a telescope taken out of a warm room is never at its best till it has cooled down to the temperature of the outside air, and this applies especially to reflectors.

Photo by *W. H. Steavenson.*

THE EQUATORIAL REFRACTOR OF DR. W. H. STEAVENSON'S OBSERVATORY AT WEST NORWOOD.

A six-inch refractor by Wray, of 9½ feet focal length. The clock will be seen under the lower bearing of the polar axis, and its weight hangs down inside the pier. The posts round the telescope are for the support of the rails carrying the "run-off" shed which houses the telescope when not in use.

The observer who uses a refractor will very soon find that on cold nights, especially when there is little or no wind, and the dew lies heavy on everything around, the object-glass quickly becomes covered with a layer of dew which seriously interferes with the efficiency of the instrument. The cure for this is what is known as a "dew-cap." This is simply an extension of the tube beyond the object-glass, which has the effect of protecting the glass from radiation in a vertical direction. It should be of some light material—zinc is very good—and blackened inside to avoid reflections, which on a moonlit night might introduce stray light into the tube and impair the brilliance of the image. The dew-cap should be an easy fit on the object-glass cell, just tight enough to remain in place, but not so tight as to risk impairing the adjustment of the object-glass when it is shipped or unshipped. Its length should be at least 2½ times the aperture of the object-glass. Occasionally, when the dew is very heavy, the dew-cap does not altogether prevent dewing of the glass; in such cases a roll of dry flannel or other absorbent material, preferably warmed, may be pushed into the dew-cap for a few minutes, when the dew will be cleared off. Even the heat of the hands applied to the outside of the tube will often have this effect if the dewing is only slight. If, as sometimes happens on a cold night, owing to the warmth of the observer's eye, the eye-lens becomes dewed, it should be warmed to drive the dew off; and if, as often happens in the case of a reflector in an iron tube, the flat becomes dewed, the hand may be cautiously applied to the flat mount for a few minutes, care being taken that the silver film is not touched. It cannot be too urgently impressed on the novice who uses a reflector that when either mirror is dewed, its surface must on no account be touched *with anything whatever,* or the silver film will be at once damaged.

A dew-cap on the finder saves much trouble, though not usually fitted.

Object-glasses and eyepieces—especially the former—should be wiped as little as possible, and then only with the softest possible materials, kept free from dust: otherwise scratching of the surfaces is only a matter of time. The object-glass should never on any account be removed from its cell, except

by an expert. Its lenses are valuable things, and are fitted to the cell by the maker with the utmost care to ensure the best possible performance—the slightest hurry or want of care may convert a delicate operation into a disaster.

A refractor, if too large to carry easily, may be left in the open air without fear of damage, if the object-glass is protected by a well-fitting cap in which a pad of absorbent material is placed to keep the glass dry. The brass work of the stand—of which there is generally far too much at the present time—will lose its bright appearance, but not its efficiency, if well designed. Iron-work, of course, should be painted, and, if well made *and well cared for,* will last almost indefinitely. The stand of the writer's nine-inch reflector is entirely of iron, and has been almost constantly kept in the open air for the last twenty years. It now works as well as on the day it was completed.

The mirrors of a reflector should always be protected by closely-fitting caps, preferably with pads of absorbent material inside them to take up any moisture that may be present. It is important that these caps should at the same time be an " easy " fit, or there is some risk of altering the adjustments of the mirrors in taking them on and off.

Photo by] [*W. H. Steavenson.*

THE " RUN-OFF " SHED AT DR. STEAVENSON'S OBSERVATORY.

The shed, which is high enough to cover the telescope when the latter is placed horizontal, is here shown in position over it.

Although, as stated above, the amateur who contemplates serious work will find a reflector of from eight to ten inches aperture probably the most suitable instrument for his purpose, it must be admitted that the adjustment of a reflector may present some little difficulty to anyone unaccustomed to optical instruments. The following directions for adjusting the mirrors are here given in the hope that they may serve to smooth away some of the initial difficulties.

Reference to the diagram given of the action of the Newtonian reflector will indicate that in order that the instrument may perform properly, the axes of the main and eyepiece tubes must intersect in the centre of the former ; these axes are usually set at right angles by the maker. Further, a ray of light incident on the speculum along the axis of the main tube must be reflected straight back along this axis, which means that the speculum—to use a rather loose expression—must be at right angles to the axis. Again, the flat mirror, which will be inclined at forty-five degrees to the axis of the tube, will present to an eye at the centre of the speculum a circular outline ; to avoid unsymmetrical interference with the beam of parallel rays incident on the speculum, which might cause want of symmetry in the image of a star, the centre of this circle—which is very nearly the centre of the flat—must be on the axis of the tube. The first thing to do, therefore, is to place it so. The flat is usually mounted in a short metal cylinder, cut off at an angle of forty-five degrees with the axis, and supported by three steel strips extending to the sides of the tube, kept taut by nuts outside the tube, and presenting their edges to the incident light.

(Whether this is the best way of supporting the flat is very doubtful, although it is commonly adopted ; in the writer's 9-inch reflector the flat is mounted on a single stout arm fixed to one side

of the square wooden tube, and this, although it intercepts a very little more light than the strips above described, is just as efficient optically, much more easily fitted, and more rigid.)

Adjustments are usually provided outside the tube by which the three strips can be made longer or shorter: by means of these the centre of the flat may, with the help of compasses or a scale, be set in the axis of the tube.

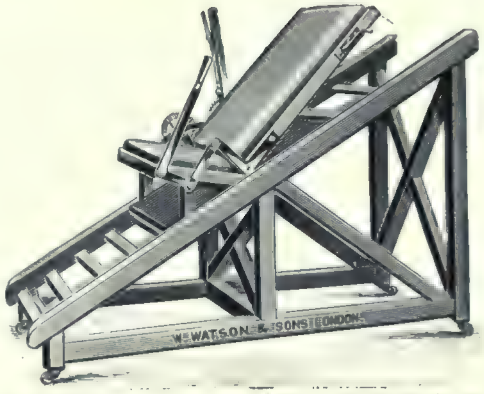
Here it may be remarked—though this point is, or should be, attended to by the maker—that the flat mirror must be of sufficient size to embrace considerably more than the whole beam of light from the speculum to the central (or axial) point of the image of an extended object. If the flat is too small, then although the centre of the field of view may receive the whole of the light from the speculum, the margin will not do so: much of the light will fail to fall on the flat, and there will be a marked deficiency of light at the margin of the field of view. As a general rule, with specula of the usual aperture and focal length used by the amateur, the flat—which is elliptical in outline—should have its smaller diameter, or "minor axis," not less than one-sixth of the diameter of the speculum, and one-fifth would be better. As is well known, an ellipse inclined at forty-five degrees to the line of sight will, if it is to appear to the eye as a circle, have its major and minor axes, or longer and shorter diameters, in the ratio of 1·414 to 1: so that for a 9-inch aperture the flat would be about 2·55 inches in length and 1·8 inches in width. Of course, the larger the flat, the more light it will stop from reaching the speculum: but in the case considered of a flat whose minor axis is one-fifth of the aperture, only one-twenty-fifth of the incident light is lost, a proportion quite negligible for most purposes; while for low power work—especially the observation of variable stars—the uniform illumination of the field of view given by a large flat is a great advantage. The flat being now centred in the main tube, we have to adjust its inclination so that a ray along the axis of the main tube will be reflected along the axis of the eyepiece tube. Adjusting screws are usually provided on the mount of the flat for this purpose. Provide a disc of metal, with a small hole (about a twentieth of an inch in diameter) in its exact centre, which can be screwed or pushed into the eyepiece tube in place of the eyepiece: the mount of a high-power eyepiece with the lenses removed will serve very well. If the eye is applied to this aperture, the farther end of the eyepiece tube will be seen as a circle, and, beyond it, the (apparently) circular outline of the flat. Inside the latter will be seen—at least if the flat is roughly adjusted—another circle, which is the outline of the speculum in its cell: to guide the eye, it is a good plan at this stage to cover the speculum with a disc of white paper of exactly the same diameter. By means of the adjusting screws on the mount of the flat the latter may now be gently tilted until the outline of the *speculum* is concentric with the outline of *the farther end of the eyepiece tube*, and well within the outline of the flat, though not *exactly* concentric with the latter: to perform this adjustment it may be necessary to shift flat or eyepiece

Photo by] [*W. H. Steavenson.*

THE "RUN-OFF" SHED AT DR. STEAVENSON'S OBSERVATORY.

The shed is here run back on its rails and the telescope ready for use. This form of shelter gives practically all the advantages of the usual observatory with its revolving dome, and is of course much less costly.

tube—whichever is capable of movement—up or down the main tube. When this adjustment is completed, the outline of the flat should not be quite concentric with the outlines of the eyepiece tube and speculum, but *slightly* displaced in the direction of the upper end of the tube. We now have the flat correctly placed so as to reflect a ray proceeding along the axis of the main tube in the direction of the axis of the eyepiece tube, and may proceed to the final adjustment—that of setting the speculum at right-angles to the axis of the main tube.



By courtesy of [*Messrs. W. Watson & Sons.*

AN OBSERVING CHAIR.

A convenient adjustable observing chair for use with a small or moderate-sized refractor. Both the height of the seat and the inclination of the back can be altered to suit the altitude of the object.

Remove the disc of paper covering the speculum, and direct the telescope to the sky or a fairly bright surface. On looking through the aperture the observer will see, within the three circles just mentioned, a very much smaller dark circle; this is the image of the flat, reflected first in the speculum and then in the flat itself; the strips supporting the latter will be seen as radiating straight lines. The image of the flat has now to be placed in the centre of the image of the speculum and of the outline of the farther end of the eyepiece tube, and this may be done by means of the three adjusting screws always provided on the cell of the speculum. It is almost impossible to give any general rules as to which of these screws should be turned, and in which direction; this will be soon found out by the observer, after a little trial and practice; but the following may be of assistance. In general, if the speculum is out of adjustment, the image of the flat will be nearest to some definite point on the circle formed by the outline of the speculum; this point can be marked by moving the hand round the upper end of the main tube, in such a manner that a finger encroaches on the aperture. The finger will be visible by reflection in the mirrors. Note the corresponding point on the cell of the speculum, and *pull this point back* *i.e.*, downwards, or away from the flat. After a few trials the image of the flat will be properly centred, and the mirrors are now in adjustment.

Photo by *W. H. Steavenson.*

DOME OF THE EIGHT-INCH REFRACTOR AT HEADLEY OBSERVATORY.

This dome contains the eight-inch Cooke refractor belonging to the Royal Astronomical Society. It is employed in measurement of double stars and observations of the planets, especially Jupiter. The small room on the left contains a transit instrument for time-determinations.

The adjustments just described may at first sight seem somewhat difficult and complicated, but a very little patience and practice soon removes the difficulty; and if a reflector is to perform at its best, they must be carefully attended to. No badly-adjusted reflector will give a really good image of any celestial object. And here it is as well to remind the owner of an equatorially mounted reflector that any alteration of the adjustments of the mirrors—especially of the large speculum—will affect the accuracy of the readings of the R.A. and declination circles; so that if the telescope is to be required to find objects by day, or faint objects at night, by means of their Right Ascension and Declination, the verniers of these circles must be re-adjusted after every re-adjustment of the mirrors; and the same applies to the finder.

Whether we adopt the refractor or reflector, the finder—which, as its name implies, is a small telescope of low power and large field carried by the tube of the larger instrument for the purpose of quickly directing it to any desired object—

must be carefully adjusted so that its axis is parallel to that of the main instrument. The method adopted for mounting and adjusting the finder varies a good deal according to the whim of different makers: often it seems to be the object of the maker to make the adjustment of the finder as difficult as possible. By far the best way of mounting a finder is to carry it in two rings mounted on short stems projecting from the main tube, these rings being somewhat larger internally than the tube of the finder, which is gripped by the rounded points of three milled-headed screws passed inwards through each ring. Why this method is not more adopted it is difficult to say; possibly it does not look "pretty" enough, which seems too often to be the consideration governing the design of a telescope. But it is certainly most efficient: no spanner or screw-driver is needed to effect the adjustment, which is admirably permanent; the finder can be at once removed by loosening two of the screws; and this mounting is particularly strong and shock-resisting, and very easy to make.

Photo by *W. H. Steavenson.*

THE DOME OF THE TWELVE AND A HALF INCH REFLECTOR AT HEADLEY OBSERVATORY.

This contains a twelve and a half inch equatorial reflector by G. Calver, with driving clock (see page 740).

In most finders it will be found that both object-glass and eyepiece are capable of being separately focussed; the eyepiece should first be focussed on the "cross wires" which mark the centre of the field of view, and a star should then be brought into focus by adjusting the object-glass.

To adjust the axis of the finder, the Moon is a great help, as the main telescope can be so easily directed to her disc. The Moon being brought to the centre of the field of the lowest power (which should have a large enough field to embrace the whole disc), the finder may then be set roughly into parallelism by means of its adjusting screws. It will then serve to bring the Pole Star (which is specially suitable for this purpose on account of its very slow motion) into the field of a low power on the main telescope, when the star can be centred in the latter and the adjustment of the finder improved—to be finally perfected by means of a high power on the main telescope.

A finder is an absolute necessity for any telescope of three inches aperture and over. It should have an aperture of not less than one and a quarter inches—one and a half or one and five-eighths are better—a magnifying power of about eight diameters, and a field of view of at least five degrees. With a good finder the whole of Orion's belt should be included in the field of view. The eyepiece of the finder may with great advantage be made of the same gauge as those of the main telescope, so that it can be used to give a low power on the latter; and the finder should, as remarked earlier, be fitted with a dew-cap.

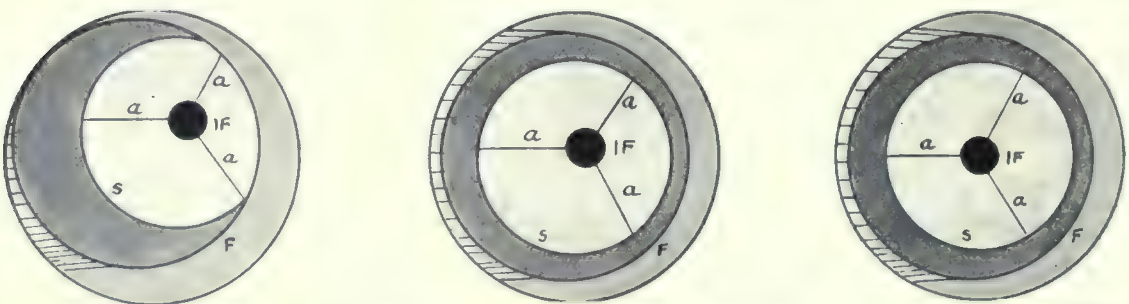
Photo by *W. H. Steavenson.*

HEADLEY OBSERVATORY.

A general view of the Rev. T. E. R. Phillips' observatory. At the time when this was taken the eighteen-inch reflector had not been erected.

From time to time in the present chapter the expressions "good nights" and "bad nights" have been used. It will not take the newcomer to the ranks of observing amateurs long to discover for himself what these expressions mean: the second of them, unfortunately, will soon explain itself. Quite apart from clearness or transparency of the atmosphere, the quality of the images seen through even the best telescope will be found to vary to a surprising extent—much more than is popularly supposed. Often the observer hears one of his friends remark, "what a splendid night you had last night" —whereas the unfortunate observer knows only too well

that he was able to accomplish little or nothing. The fact is, that as a rule the most *brilliant* nights are very often the worst. The images, with even moderate powers, are tremulous and blurred, and fine details are obliterated in the continuous disturbance of the image. This condition of things is described by saying that the " seeing " is bad. The quality of the seeing depends on many things—the location of the observer ; the force and direction of the wind ; his proximity or otherwise to houses or towns ; the state of the barometer and the temperature and humidity of the air ; and last, but not least, the time at which the observations are taken. As a rule, observers in towns do not get the best " seeing " until after midnight, on account of the heating effects of the numerous chimneys, each of which is " doing its bit " towards the general disturbance. Usually in Great Britain the eastern parts of a large town suffer more in this way than the western, the westerly winds which generally prevail bringing the heated vapours in the direction of the observer's locality. Bad seeing is often experienced near the seashore, and though it might be thought that high ground would be advantageous, it is not always so. As a rule the best seeing is experienced on still, cold nights in winter, when there is just sufficient mist to blot out stars of the fifth and sixth magnitudes to the unaided eye. On a foggy night the seeing is often excellent ; but on such nights it is hopeless to apply very high powers, say, to the planets, as the available light in the image is so much reduced by the fog. Excellent seeing is often obtained just after a westerly gale, and high wind, although it shakes the telescope, is often no detriment to good images. Denning has recorded that he has often found planetary markings



[*M. A. Ainslie.*

ADJUSTMENTS OF A NEWTONIAN REFLECTOR.

These figures show the appearances seen through a small hole placed in the usual position of the eyepiece. E is the circular outline of the farther end of the eyepiece tube ; F that of the flat mirror ; S that of the speculum ; I F the image of the flat mirror seen by reflection in the speculum ; *a a a* the thin metal strips supporting the flat mirror. A—Mirrors out of adjustment. B—Flat mirror adjusted, but not the speculum. C—Both mirrors in adjustment. (The displacement of F towards the upper end (*i.e.*, to the left) of the tube is somewhat exaggerated in figures B and C.)

well seen through the smoke and fog of Bristol. So it will be seen that there is no hard and fast rule for the kind of weather that produces good seeing, and the observer must take all the chances he can, remembering that on brilliant nights when there is much scintillation, although detail may be invisible and star images hopeless with high powers, star clusters and nebulæ are to be seen at their best, requiring, as they do, low powers, and light rather than definition. Possibly the most hopeless nights are those on which there is a bright full moon, but bad seeing ; on such there is really very little for the amateur to do.

Every observation should, of course, be recorded, if any use whatever is to be made of it ; and the record should always be accompanied by a statement of the climatic conditions prevailing at the time, and the quality of the seeing. Most observers adopt a scale of numbers for recording the latter, from 0 to 10. These numbers, when first suggested, were based mainly on the quality of star images, as regards the visibility and steadiness of the diffraction rings round the disc and the quality of the disc itself ; but for most purposes the numbers may be arranged as follows, it being supposed that an aperture of about eight and a half inches is in use.

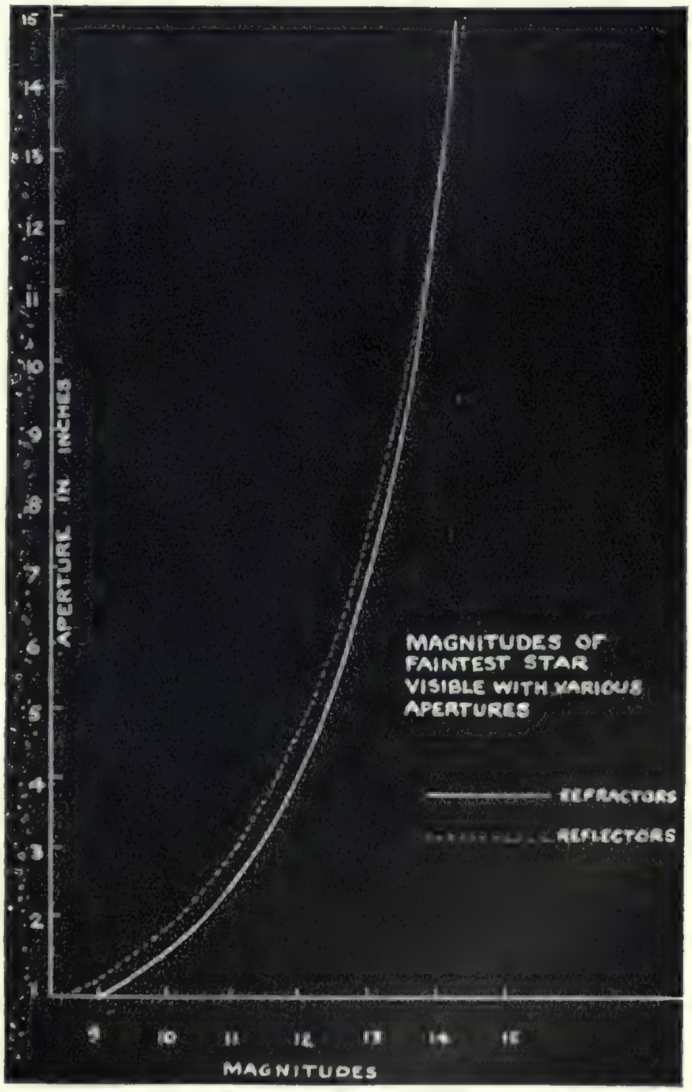
0, 1, 2 } Conditions varying from absolute hopelessness to the possibility of seeing *some* detail on a planet, such as Jupiter.

3 The image exhibits some of its finer details, perhaps for two or three seconds every minute or two.
4 Image generally disturbed, but with occasional steady intervals, for a few seconds at a time.
5 The good intervals are longer, say half a minute or so.
6 Images good most of the time, with occasional short periods of disturbance.
7 Images very good, except for occasional flickers and jerks.
8 Images quite steady for long periods, with hardly a trace of disturbance even with high powers.
9 Not often recorded: the same as No. 8, " only more so."
10 Absolute perfection; often dreamed of, but never realised.

But it must be remembered that although these numbers are valuable to the observer himself, they are really only expressions of his personal opinion: different observers will differ enormously as to the number they assign on a given night, even with the same aperture in use; and when different apertures are used, the differences are greatly increased. An observer with a four-inch refractor might record 7 or 8 at the same time that another in the same locality, but using a ten-inch reflector, might record 4 or 5. To give any information to others, the observer should, besides assigning a "seeing number," record his aperture, and power, and whether he used a refractor or reflector.

For every aperture there is a *minimum visibile* in the way of faint stars. This varies with different eyes, on different nights, and with different qualities of object-glass or mirror; but as a rough guide, it may be said that a good four-inch object-glass, on a really transparent night, when the "seeing" is good and images steady, should just render visible stars of magnitude about 12·0, in the absence of any bright object in the field of view which might dazzle the eye by its glare. Haze, light clouds, or mist, will absorb much of the light of the star: and "bad seeing" will expand the image and reduce its contrast with the surrounding darkness. As a rule, fainter stars are to be seen in the country than in towns.

The curve on this page represents the magnitudes that can usually be seen with various apertures, under first-class conditions; in the diagram



M. A. Ainslie.

LIMITING MAGNITUDES WITH VARIOUS APERTURES.

This curve shows the magnitudes of the faintest stars visible under ordinary conditions with refractors and reflectors of various apertures. It will be seen that up to about twelve inches the advantage is with the refractor. With larger apertures the absorption of light by the object-glass of the refractor causes the reflector to be rather superior in light-grasp. The curve, which is only to be taken as giving an average, is based on the assumption that a refractor of one inch aperture will just show a ninth magnitude star, and a reflector one of magnitude 8·5.

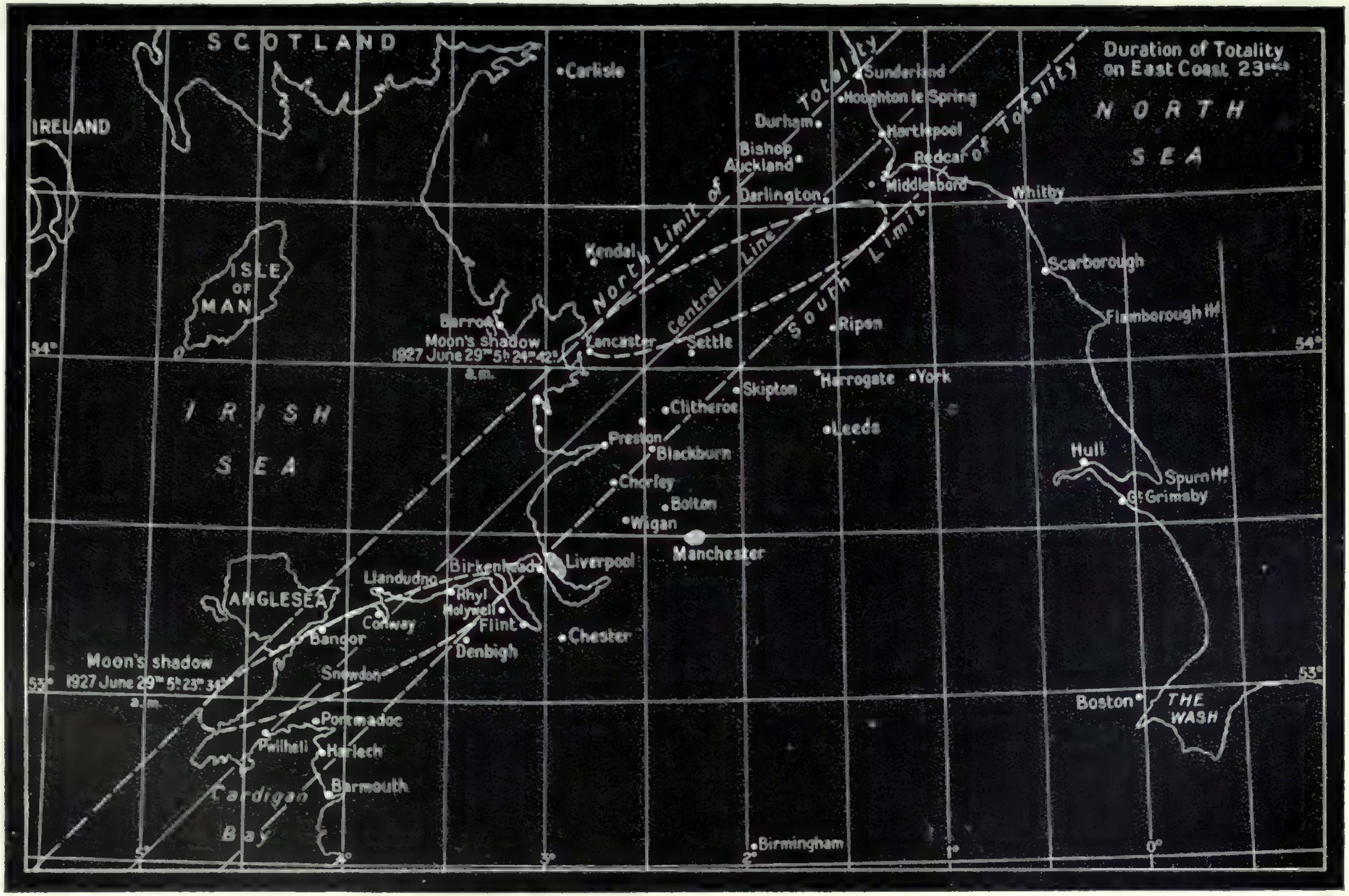
the Harvard scale of magnitudes is used, according to which, as explained in Chapter XV, a star of given magnitude appears 2·512 times as bright as a star one magnitude fainter. Reflectors, except in large sizes, do not show quite such faint stars as refractors of the same aperture.

Whether an observatory is necessary or even desirable for efficient observation is a question on which opinions vary considerably. That it is a convenience there is no doubt: but it need not be a very elaborate affair. In any case it is as well that the structure should be as light as possible consistent with sufficient strength and durability, so that internal and external temperature may be the same; a light wooden hut, with a revolving roof that can be turned in any direction, or a light roof made to slide right off, will amply suffice. If the expense of such an "observing hut" is considered too great, a very efficient substitute consists of a simple wooden shelter, just large enough to contain the telescope, running on rails so that it can be easily pushed aside when observations are commenced and as easily run over the telescope when done with. But many amateurs have done, and are doing, excellent work entirely out-of-doors: and if the observer is careful to protect himself from cold winds and "night air" by suitable clothing, he need fear no ill effects, assuming that he is fairly strong in constitution: in fact, it is at least probable that night air is actually beneficial to most people. A telescope, if well designed and well cared for, suffers no detriment from being left in the open,

By courtesy of *Mr. G. Calver.*

ALTAZIMUTH MOUNTING FOR MODERATE-SIZED REFLECTOR.

An extremely efficient form of mounting, with slow motions in altitude and azimuth. The former is given by the milled head under the upper part of the tube, its clamp being shown lower down; the latter by a screw worked by the handle shown resting on the ground. The writer's nine-inch reflector is mounted on a stand of this type. The arrangement of the slow motion in altitude greatly conduces to steadiness in a wind.



[A. C. D. Crommelin.

TRACK OF THE TOTAL SOLAR ECLIPSE OF 1927, JUNE 29, ACROSS WALES AND ENGLAND.

After a blank period lasting from 1724 there will be a total solar eclipse in England in 1927 (*see* chapters on Solar System and Earth-Moon System). The central line runs from Pwllheli to Hartlepool, and totality is observable for about fifteen miles on each side of this line. The Sun will be rather low down; it will be highest and totality longest on the east. Stonyhurst Observatory lies within the zone of totality. British amateurs will no doubt take full advantage of the rare opportunity thus afforded. The succeeding English totality is in August, 1999 (Cornwall).

Photos by kind permission of *G Merton, Esq., Cambridge.*

AN OBSERVING HUT WITH "SLIDE-OFF" ROOF.

A simple and efficient observatory for a small telescope, with roof in two parts, sliding off on the rails as shown.

Here the roof is slid off to each side and the telescope ready for use. The telescope is a six-inch equatorial refractor, by Cooke.

while there are good grounds for believing that as a rule "seeing" is better in the open than in an observatory, this applies more especially to reflectors, which, if used in the open, should (as already mentioned) have wooden tubes. Most observers will have their own ideas as to suitable clothing for cold weather; but cloth boots, thick stockings, a warm overcoat, and—last but by no means least—a knitted woollen helmet covering the face as well as the head, will enable the observer to defy any cold weather that he is likely to meet with.

If observations are carried on in the open, it will be found convenient to have, near the telescope (preferably to the north of it) a strong table, with an open box laid on its side fixed on it. This affords shelter for note-book, maps, &c., and protects them—as well as such things as eyepieces and the like—from dew. For reading catalogues, making notes and drawings, and consulting maps, a small lamp—which may be of the pocket electric form now so common—is of course an essential: and it should be covered with a red shade, to avoid the glare of the white paper, which is very liable to impair the sensitiveness of the observer's eye. The writer has used a photographic dark room lamp with much comfort.

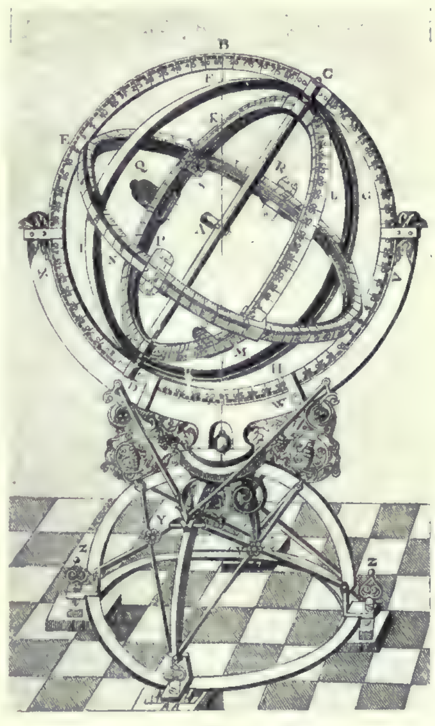
It is hardly necessary to remind the observer who wishes to do serious useful work in Astronomy that it is of the greatest importance that full notes should be made *at the time* of anything in the nature of an observation, whether the phenomenon observed is of a usual or unusual nature. Nothing should ever be trusted to memory for more than a few minutes. A rough note-book should invariably be at hand when the telescope is in use, and the notes in this should be transferred to the fair note book as soon as possible. The writer has found it a good plan, when making drawings of planets, to have several blank forms ready, and to note down on these as rapidly as possible the various details visible as they are seen: often four or five such forms are used for a single drawing. These are then taken indoors to a good light, and a drawing made which represents as far as possible the various details seen, aided of course by the memory, which may be relied on for a few minutes at any rate. This drawing is then finally compared with the actual view of the planet itself, and any corrections made that may be required, due allowance being of course made for the axial rotation of the planet—in the case of Jupiter a most important point. In this way one can be fairly certain that the result represents the actual aspect of the planet, so far as the telescope and eye were capable of seeing it on the particular occasion.

On really exceptional nights, when, to use a common phrase, a planet looks "like a steel engraving," much more detail is sometimes visible than can be represented on the drawing; on such a fortunate occasion—which will not occur too frequently—it is well to concentrate attention on one particular region of the planet and to make a survey of this on a larger scale, rather than to attempt, in the limited time available, a representation of the whole disc: for it must be remembered that in the case of Jupiter, an interval of half an hour makes a very considerable change in the aspect of the planet.

The observer will probably find that his early attempts at depicting what he sees will prove somewhat disappointing, and will fall far short of published drawings—which are, it must be admitted, sometimes rather over-elaborated, doubtless for pictorial effect. But if his aim is throughout to depict what he sees, all that he sees, and *only* what he sees, he will soon find that " practice makes perfect," and that his sketches and records will grow in value as his experience increases.

In our changeable English climate, in which cloudy and clear skies at times follow one another with such rapidity, the observer should at all times be ready for what fortune and the weather may bring him; often he may, quite unexpectedly, and in the midst of very adverse conditions, find a few minutes, or perhaps a half-hour, of really first-class seeing: and he will soon realise the advantage of having a " working list " ready prepared for such emergencies. If, for example, he is interested in variable stars, he will have their positions carefully marked on a good map, or—if he enjoys the luxury of an equatorial stand with divided circles—he will have their positions ready to hand on a special list, so that he will not be under the necessity of wasting time in hunting up catalogues. No time spent in the preparation of working lists is ever wasted. His telescope should be kept properly adjusted, and ready for use at a moment's notice; his observatory—if he has one—should be in good order, so that the roof or its shutters may not give trouble; his eyepieces in their proper places and their lenses properly cleaned. His rough note-book should be ready and its pencil—which should be tied to it—a simple precaution, but one which will be appreciated on a dark night—sharpened. A separate " fair " note-book should be kept for each branch of observation: for example, observations of Mars and Jupiter should not be found in the same book. This is quite an important point when—as is to be hoped will be the case—the observer sends in his observations to the Director of the appropriate Section of the British Astronomical Association.

Finally, *Labor Ipse Voluptas.* The Amateur Astronomer has been well described by Professor Hale as " the man who works in Astronomy because he cannot help it, because he would rather do such work than anything else in the world, and who therefore cares little for hampering conditions of any kind." Exasperating weather, icy winds, and cruel " seeing " do not avail to curb his enthusiasm. There are by no means too many such; if the writer of this chapter has added even one to the list, his labour will not have been in vain.



AN ASTROLABE.

The Astrolabe was among the earliest of observatory instruments, properly so-called. It was provided with divided metal circles, corresponding to meridian equator, ecliptic, etc., on the star-sphere. By rotating these circles, which were fitted with sights, the Righ. Ascension and Declination of objects (or, alternatively, their longitude and latitude) could be measured with moderate accuracy. The instrument above belonged to Tycho Brahé, but it is believed to be very similar to the one used by Hipparchus 1,700 years earlier.

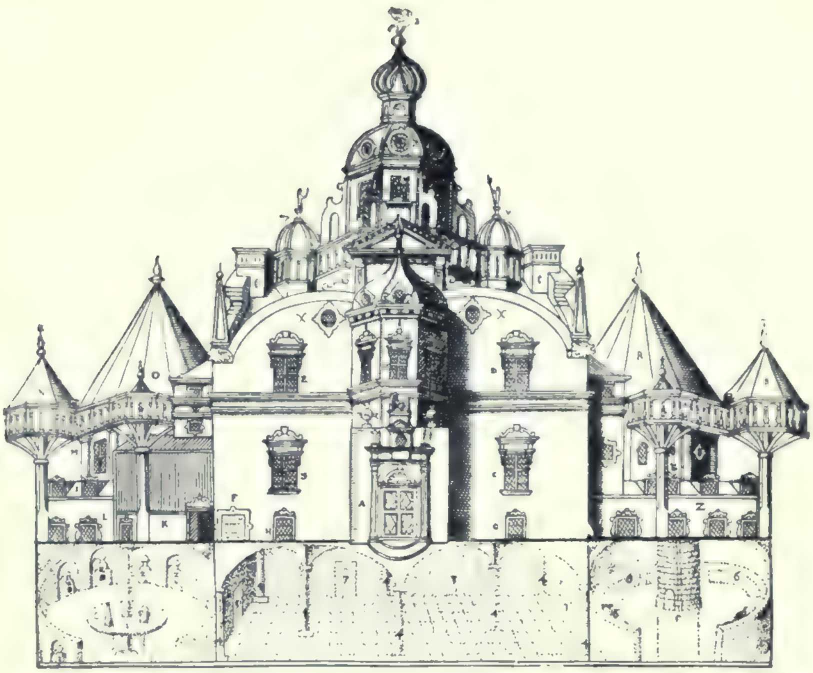
CHAPTER XXI.

OBSERVATORIES AND THEIR WORK.

BY DR. W. H. STEAVENSON, F.R.A.S.

THE contemplation of an intricate and well-made piece of mechanism is apt to lead, very naturally, to a desire to inspect the factory in which it was produced, and to watch the workers as they fashion the several parts that are finally to be assembled in the completed product.

The structure of modern Astronomical Science, as presented to the reader in the preceding chapters of this Work, is essentially an assemblage of a large number of separate



From "Astronomy for All." By permission of Messrs. Cassell & Co. Ltd.

TYCHO'S OBSERVATORY.

In 1576 the Observatory of "Uraniborg" was built for Tycho on the Island of Hven, in the Sound, by his patron the King of Denmark. It was on the observations made here during the succeeding twenty years that Kepler based his famous laws of planetary motion. All Tycho's work had to be done without the aid of the telescope, which was not invented until 1608.

facts, each due either to some individual astronomer or to a group of specialists. Observatories are, so to speak, the factories that are responsible for the production of such data, which are there and then (or subsequently) fitted into the general structure of which they form the necessary parts. Some facts, therefore, with regard to modern observatories, and the work of those who labour therein, may be of interest.

To the average layman a certain atmosphere of mystery undoubtedly attaches to an astronomical observatory. This is probably due in part to the fact that such institutions are not as a rule open to public inspection, especially during working hours, and also perhaps to the fact that the work done, though important from a scientific point of view, is seldom of a kind that is sufficiently spectacular to attract the attention of the Daily Press. In consequence, few persons get beyond the general impression that an observatory is a place where astronomers sit up all night, intent on the discovery of new objects with gigantic telescopes. There is certainly something fascinating in such a picture, but it is ludicrously far from being a truthful one. In actual fact a large part of the work of an average observatory is done during daylight hours, and consists in the lengthy mathematical treatment of observations that took but a few minutes to secure, or in the measurement of photographs taken, perhaps, during a brief clear interval some days or weeks before. Many a professional astronomer goes through his entire career with little or no "star-gazing" in the popular sense of the term; and, as for the discovery of new objects, very few observatories include this as even a minor part of their programme of work. True, the "gigantic telescope" is not entirely mythical, but, on the other hand, it is not every observatory that is fortunate enough to possess one of these, and much of the most important work has been and is still being done with instruments of very modest dimensions.

What, then, actually goes on behind the walls of a modern observatory, and to what purposes is its work really directed? The answer to this question involves a considerable retrospect, for the astronomical observatory was, like other institutions, evolved from simple beginnings, and has been steadily developing throughout the centuries. Strictly speaking, the word "observatory" applies to any place from which observations are made, with or without instruments. Such a general definition would, of course, apply even to the open fields from which the ancient Chaldeans watched the heavens. However, it is more usual to associate the word with a fixed position in which an instrument of some kind is mounted for systematic use. But, even in this narrower sense, the observatory is a very ancient institution, being at least five thousand years old and probably of still greater antiquity. There is

plenty of evidence to show that the ancient Egyptians, Babylonians and Chinese observed with instruments of some sort very many centuries before our era. We know very little of the nature of these instruments, which were doubtless of a very rough description ; but improvements were gradually introduced, and the divided circles and quadrants used by Eratosthenes, Hipparchus, and Ptolemy were capable of giving reasonably accurate results considering their small size and the necessary limitations of the unaided eye. In the succeeding centuries divided instruments of this type were still further improved in size and accuracy, culminating, in so far as the precision of results in observation is concerned, in the quadrants of Hevelius and Tycho Brahé, which reduced the errors of the observed positions of stars to about one minute of arc. This brings us to about the beginning of the Seventeenth Century, and it was at this point that a complete revolution in the equipment of the observatory was brought about by the invention of the telescope. Hitherto the accuracy of observations depended on the precision with which two sights could be aligned on a star with the unaided vision, and naturally minute deviations from such alignment were imperceptible. Now, however, by substituting a telescope for the rough sights, much smaller differences of direction were made manifest, so that, given a well-divided circle, observations could be made that were accurate to within a very few seconds of arc.

It so happened that this great increase in the precision of astronomical instruments occurred at a very opportune moment. Oceanic navigation was a comparatively new thing, but the one circumstance which did most to check its rapid development was the danger and delay due to the impossibility of determining the exact longitude of a ship when many days out of sight of land. Under such conditions the heavenly bodies were the mariner's only definite guide, and it soon became obvious that correct determination of their positions was of vital importance to him. Catalogues of the brighter fixed stars were already available, and they were quite sufficiently accurate for the determination of *latitude* ; but finding the longitude was quite a different matter, for it involved a knowledge of the exact *time* at some definite meridian, the difference between this and the local, or ship's, time (deduced from the altitudes of stars, etc.), giving the desired difference of longitude. A

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THE OBSERVATORY OF HEVELIUS.

A typical open-air observatory in the early days of the telescope, in the Seventeenth Century. Astronomical instruments were still roughly made and poorly mounted, and it was not until the Eighteenth Century that substantial advances were made in the accuracy of observations for position.

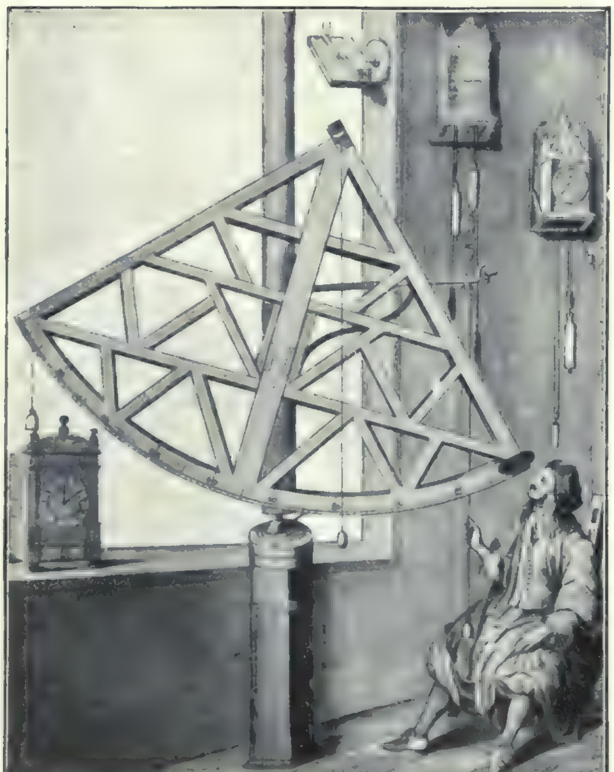
clock that would keep good time on board ship was still entirely lacking, so the only method available was the substitution of a celestial time-piece, in which the fixed stars should act as numerals and the Moon as the moving hand. It was here that the help of the astronomer was so urgently required, for the motion of the Moon is subject to many variations of a complex character (*see* Chapter V), and no tables were then available which would predict its position accurately for any given time. Therefore, the establishment of observatories for the study and prediction of the Moon's motion became a matter of national importance. The foundation of the State observatories of Greenwich and Paris, in 1675 and 1676 respectively, marked the opening of this new epoch of professional Astronomy.

Photo by] [*Carl Zeiss.*

THE "URANIA" OBSERVATORY, ZURICH.

This is an example (too rare in some countries) of an observatory devoted mainly to the use and instruction of the general public. Well equipped and endowed, it is provided with an experienced curator, who manipulates the telescope and demonstrates to visitors the chief objects of interest in the heavens.

From the point of view of the science itself this was of great importance. Hitherto astronomical research had been left largely to individual enterprise, occasionally assisted by royal patronage in certain countries. Now, for the first time, Astronomy was found to be of sufficient practical importance to warrant public subsidy. The latter resulted in an almost immediate impetus to its development, for, on the one hand, the results demanded of the astronomer involved an increase in the accuracy of theory and observation, and, on the other hand, funds were now available for the improvement of the necessary instrumental equipment. This was enormously to the benefit of exact Astronomy, which made far greater strides in the two centuries following the foundation of Greenwich Observatory than it had done in the two thousand years prior to 1675. Thus, then, was the Astronomy of position set fairly upon its feet, chiefly through the fortunate circumstance that it happened to be of practical importance from a national point of view. Meanwhile, however, a new and important branch of the science was being born. The astronomical telescope, as introduced to the world by Galileo, was a very imperfect instrument from the optical point of view, and, as we have seen in Chapter I, its development was at first very slow. In consequence, although its power of magnification made it a very



From "Astronomy for All."] [*By permission of Messrs. Cassell & Co., Ltd.*

HEVELIUS OBSERVING WITH A QUADRANT.

Instruments of this type were in many ways more convenient than the old astrolabe, and were very popular in the Seventeenth Century. Flamsteed, the first British Astronomer Royal, used a sextant, equatorially mounted, at Greenwich. The telescope had now been invented some time, but its value as an aid to precision in measurement was not quite fully realised, and Hevelius and others still adhered to the old method of bare sights.

Drawn by Rev. T. E. R. Phillips

MARS.

The drawing represents the aspect of the planet in an 8-inch refractor on March 23, 1918, at 9 hours 0 minutes G.M.T. The blue-green marking on the right is the Syrtis Major. The enclosed whitish area to the left of the centre is Elysium. At the bottom is seen the N. Polar snow-cap, with what is perhaps snow-covered high ground adjoining it. The Casius appears as a dark wedge-like marking running from the bottom right towards the centre, and connecting it with the Syrtis is the curve of Nepenthes-Thoth which has been so prominent in recent years.

useful pointer for instruments designed to measure small angles, it failed in those qualities which would have made it suitable for studying in detail the appearances, as distinct from the positions, of the heavenly bodies. It was not, in fact, until late in the Eighteenth Century that the great development of the reflector by Herschel and others, and the discovery of the achromatic principle, made the serious study of Physical Astronomy at all practicable.

The arrival of the large telescope had, naturally, a profound influence on the general progress of the science, but at this point the professional astronomer found himself in a somewhat difficult position. However much he might desire to explore the heavens with the improved instruments now available, he had to remember that his primary obligations were concerned with the accurate determination of celestial positions, for which telescopes of great size were not really necessary. Under these circumstances the expenditure of public money on large telescopes was not easy to justify to the satisfaction of those in authority. Moreover, the staffs of most State observatories were small, and their available time was already fully occupied with routine work. What was wanted was a new type of observatory which could be free to devote its time and resources to the pursuit of the new Physical Astronomy without being tied down to work that must yield purely practical results. This want soon began to be supplied by Universities and similar institutions, which undertook the erection and control of several large observatories with no other aims than the advancement of pure science and the instruction of students therein. Such observatories, though under the direct control of the institutions of which they form a branch, have in many cases owed much to private benefaction, and this applies especially to some of the larger American observatories, many of whose great instruments are the result of the munificence of certain public-spirited individuals.

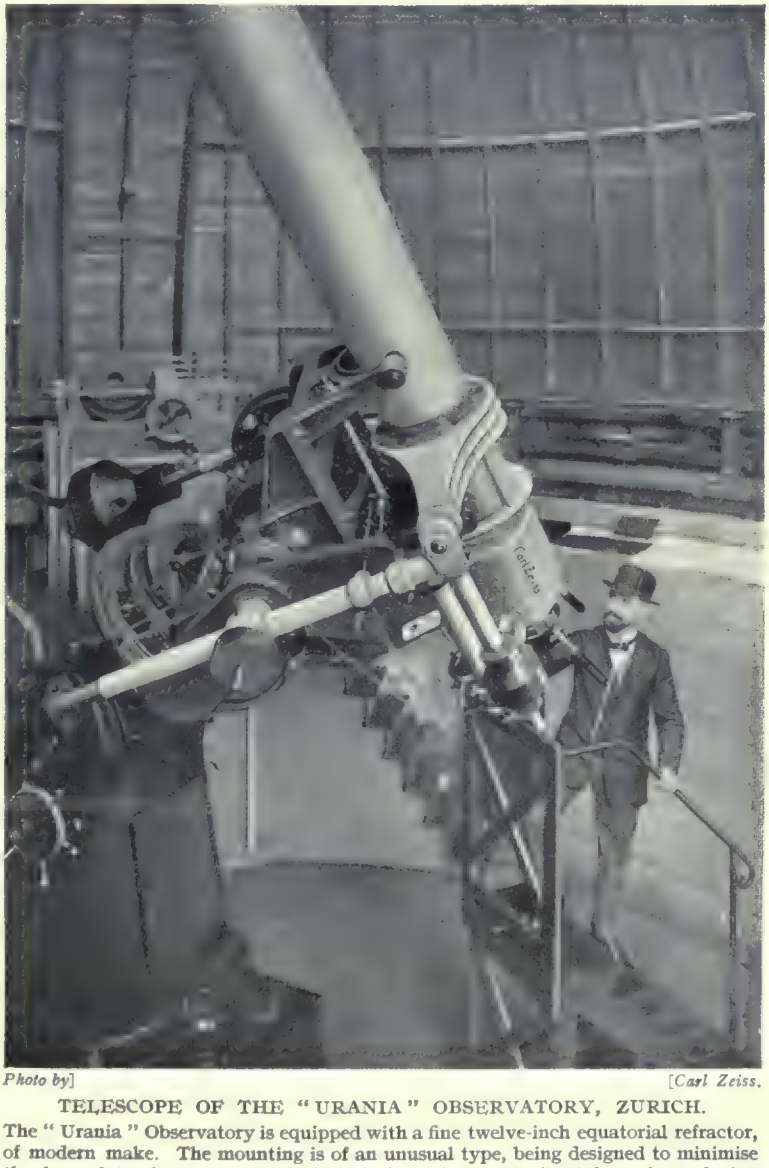


Photo by] [*Carl Zeiss.*

TELESCOPE OF THE "URANIA" OBSERVATORY, ZURICH.

The "Urania" Observatory is equipped with a fine twelve-inch equatorial refractor, of modern make. The mounting is of an unusual type, being designed to minimise the large lateral movement of the eyepiece that normally takes place during observation with a long telescope driven continuously by clockwork. This type of mounting is very heavy, as it necessitates a system of counterpoising by weighted levers, some of which are seen in the illustration.

There are, then, broadly speaking, two types of Public Astronomical Observatory: the first, State-owned and devoted mainly to the astronomy of position, or "fundamental" astronomy; the second, under academic or similar control, devoted chiefly to the physical aspect of the Science. But it may here be said that there is no sharp dividing line between the two, as regards the work done in them, and this is becoming increasingly true as time goes on. Thus, on the one hand, some of the State observatories have been able gradually to enlarge their staffs and equipment sufficiently to be able to include purely scientific research work in their programme without having to curtail their more "legitimate" activities; and, on the other hand, many observatories of the other type have been able to devote much time to the accurate determination of star-positions for the formation of catalogues, though not for purposes connected with the practical business of navigation.

The technical control of a public observatory is in the hands of an experienced director, assisted by a staff of varying (often lamentably small) size. The director, who in the case of a University Observatory usually holds also the professorship of Astronomy, may himself take an active part in observational work, though much of his time is often taken up by the responsible duties of administration, and the examination and publication of the results obtained at the observatory. The assistants work under his direction, one or more being allotted, in the case of a large observatory, to each of the principal instruments. As a rule, a certain amount of routine work is done, according to the programme adopted by the director; but, in practice, the more experienced assistants are often allowed, and even encouraged, to pursue special investigations on their own initiative, and the workers in modern observatories are happily far from being merely the "obedient drudges" for which Pond stipulated in his administration at Greenwich.

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A PUBLIC OBSERVATORY IN BERLIN.

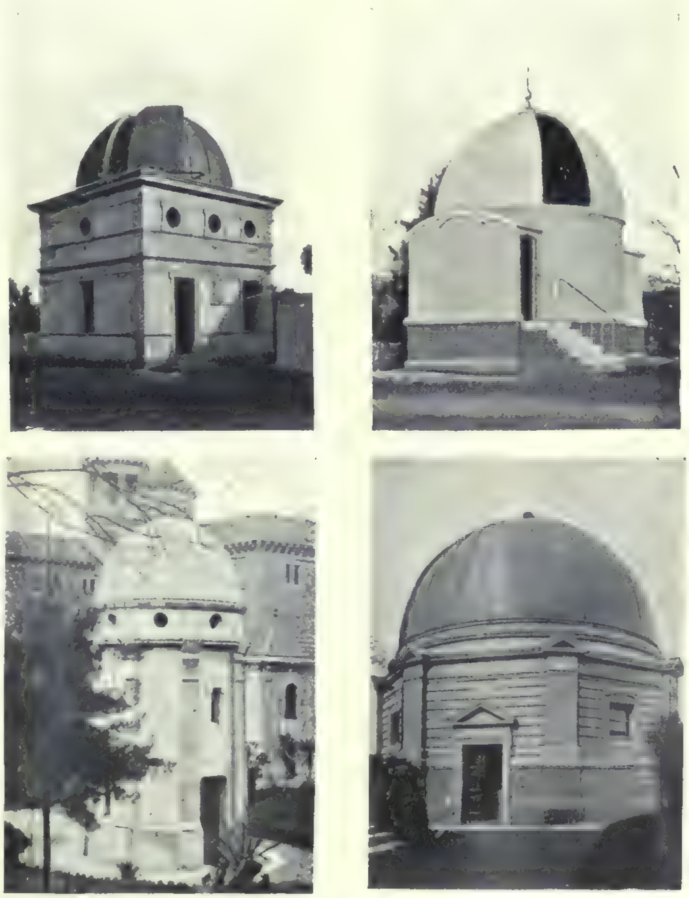
This observatory is designed for the same uses as that at Zurich in Switzerland. Germany and the United States are better provided with facilities for popular observation than any other countries.

In a large observatory the arrangement of a time-table for the observers is not the least important part of the work of the director. As has been already noted, much of the work of such an institution is done in daylight hours, and the astronomer, being only human, would soon find his health breaking down under the strain if he were compelled continuously to "burn the candle at both ends." Accordingly, his spells of day and night duty have to be carefully arranged with due regard to this aspect of the question. Moreover, this fitting in of duties is also of importance from the point of view of the various instruments of the observatory, some of which (especially the larger American telescopes) require special changes in their adjustment several times in the twenty-four hours to render them fit for different kinds of work. Thus, for instance, the great forty-inch Yerkes refractor may be used on the Sun in the day-time, a spectro-heliograph being attached for the purpose. In the evening another astronomer requires the telescope for the determination of the radial velocities of stars, which means the substitution of a stellar spectrograph. Later still the same night yet another

observer wants the instrument for direct photography (*see* illustration on page 44), or perhaps for the visual measurement of double stars. It will readily be understood that the arrangement of work in such a way as to be most convenient for astronomer and instruments, with due regard to the best interests of research, is far from being an easy matter.

As for the exact nature of the work done by individual observatories, apart from the rough general division of type already mentioned, this is determined in its details by many factors, chief among which are the situation of the observatory, the character of its equipment, the size of the staff available, and the scientific inclinations of the director and his assistants. All these are of sufficient moment to deserve special mention.

The choice of a suitable site for the erection of an observatory is of great importance from the point of view of the work to be undertaken in it. Climatic, that is to say atmospheric, difficulties are among the greatest with which the astronomer has to contend. The value of nearly all astronomical work suffers if observations cannot be carried on with reasonable continuity, and for this reason districts much affected by cloud and fog (as in low-lying regions near the sea in some parts of the world) are the least suitable as regards the number of hours available for observation in the year. Another thing to be avoided is the proximity of large towns, whose smoke obscures and whose lights illuminate the night sky. Vibration, too, caused by heavy traffic or the working of machinery close by, is apt to interfere with the more delicate observations, and even with the very adjustment of some instruments. Some of the older observatories have to put up with such things, having been built in their present positions for various good reasons unconnected with the objections here mentioned, and it is not always easy or expedient to effect the bodily removal of a large and long-established institution. Of late years, however, there has been a strong tendency, in the erection of new observatories, to choose sites with a very careful eye to their suitability from a climatic point of view. In this the height above sea-level is one of the most important points to be considered and many modern observatories have been built on or near the summits of fair-sized mountains, or on plateaux of considerable altitude. The effect of this is to raise the observer well above the level of the grosser clouds, fogs, and dust-haze, giving him a large percentage of those dark transparent nights which are so essential for the visual and photographic study of the fainter stars and nebulæ. But mere transparency (that is, freedom from cloud and



Photos by] [*Grubb.*

OBSERVATORY DOMES.

The dome, or rotating roof, of an observatory may take several forms, and in this, as in the building itself, it is often possible to combine architectural elegance with practical utility. Most modern domes are approximately hemispherical, but the simpler "drum" form, illustrated on page 153, was much used about the middle of last century, and is still occasionally to be met with. Examples are to be found at the Royal Observatory, Edinburgh, and the Lowell Observatory, Flagstaff, Arizona (*see* page 322).

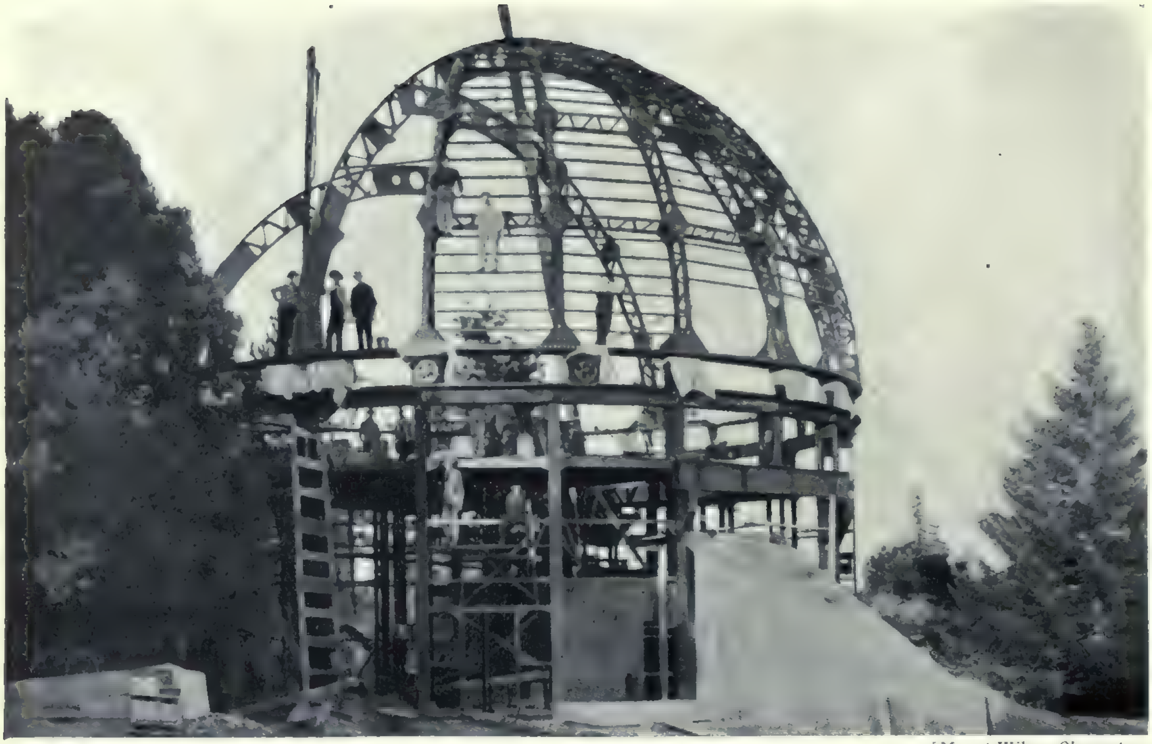


Photo by, [*Mount Wilson Observatory*.

A LARGE DOME UNDER CONSTRUCTION.

The dome of a large modern observatory generally consists of a skeleton framework of steel girders, over which is laid a covering of metal or papier-maché sheets. Such a structure may be very heavy, weighing anything up to a hundred tons and requiring the use of electric motors for its rotation. The photograph above was taken during the construction of the observatory covering the sixty-inch reflector at Mount Wilson, illustrated on page 525.

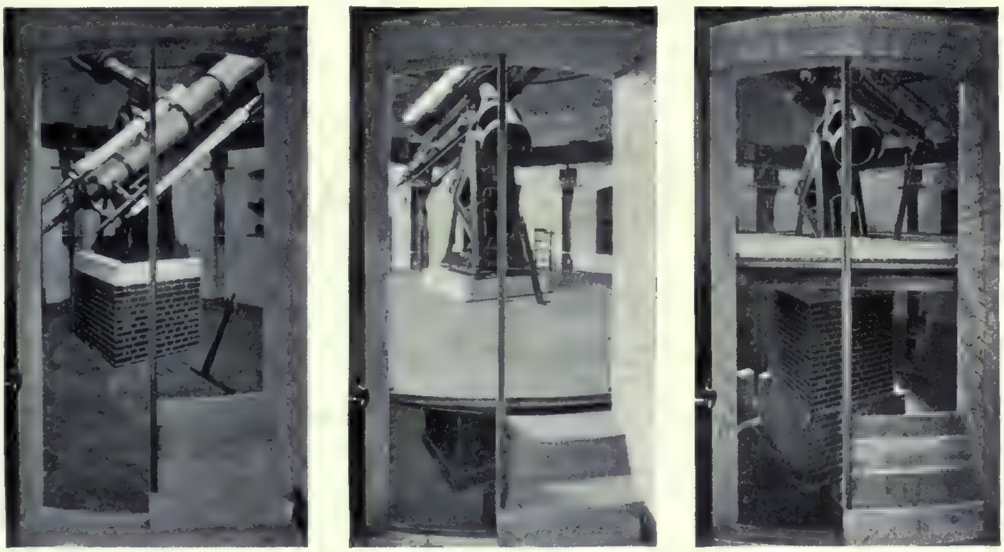
Photo by] [*Yerkes Observatory*.

THE "BURNHAM" DOME AT YERKES.

This dome, which covers the little six-inch telescope with which Burnham discovered 451 double stars, is so constructed as to allow of the maximum possible aperture for observing. It consists of two quarter-spheres of slightly unequal size, one within the other, and both rotating independently. This is a very convenient type of dome, especially for observatories of small or moderate size.

haze) is not everything, for on the clearest nights the images of stars may be greatly disturbed by atmospheric currents of different temperatures and densities, as evidenced by violent twinkling. On such nights it is impossible to do work requiring the use of large apertures and high powers, such as the measurement of very close double stars. Therefore, if such work is to be done, a site must be chosen wherein such effects are likely to occur as seldom as possible. The factors making for *steadiness* of telescopic definition are even now not thoroughly understood, but it is known that height above sea-level, angle of slope of neighbouring land, proximity of warm sea or snow-covered peaks, and character or lack of surrounding vegetation all produce their peculiar effects in this connexion. Often it will be found that the atmosphere in a particular place is more steady in the day-time than at night, or vice versa, and such differences are obviously important where a study of the Sun is to be the main work of the observatory.

Of the equipment of an observatory, in its influence on the choice of work to be done, little need be said. Of course, where money is no object, the choice of instruments is dictated solely by the nature of the investigations to be pursued, having due regard to the suitability of the site. But more generally the reverse is the case, and the astronomer is forced, like other people, to "cut his coat to suit his cloth." Obviously certain departments of astronomical research, such as the spectroscopic study of faint stars and nebulæ, and the determination of stellar parallax, demand the use of very large and well-mounted instruments, and would be quite beyond the capabilities of an observatory whose chief telescope was, say, a twelve-inch visual refractor. Fortunately, however, there is in astronomy a large amount of useful work available for instruments of moderate aperture; in fact, one might almost say that sufficient work could readily be found to keep a telescope of *any* size, however small, in constant and profitable use. Several examples of the kind of work that is actually done with very modest apparatus will be found in the description of a few typical observatories which follows later.



Photos by] A RISING FLOOR. [*Grubb.*

The eyepiece of a large telescope is constantly assuming different heights above the ground. This normally necessitates the use of cumbersome step-ladders or observing platforms that must be wheeled about the observatory. To obviate the inconvenience of this Sir Howard Grubb introduced the rising floor, whose height can be adjusted to suit that of the eyepiece, as shown in the three sections of the illustration above. In small sizes the elevating apparatus can be worked by hand.

The question of the size and nature of the staff available for the working of an observatory is clearly of the first importance. Indeed, it may truly be said that to most directors it is the most vital question of all. Certainly some modern observatories are heavily endowed, and are therefore relatively but little affected in this respect, but in the majority the handicap is felt severely. It is a tragic, but only too common, thing to find an observatory seriously hampered or even practically crippled in its work merely through the need of an adequate staff, and, under such circumstances

the heroic manner in which a single assistant will often labour steadily on, trying to do the work of two or three men, must command our highest admiration. Clearly it would be unreasonable to expect a continuous and rapid output of results from an institution so situated, and the relative inactivity of many an observatory is no discredit to the miserably small staff which works therein. And, in such cases, it is not only the work that suffers, but the instruments as well. A telescope, with its mounting, is a delicate piece of mechanism that requires constant attention if it is to be efficient in its working; it cannot but deteriorate as a result of forced inactivity. To an astronomer it is a pathetic sight to see a fine instrument steadily lapsing into a condition of complete uselessness, but, unhappily, there are many observatories in which such a sight may be seen. Persons of means who are interested

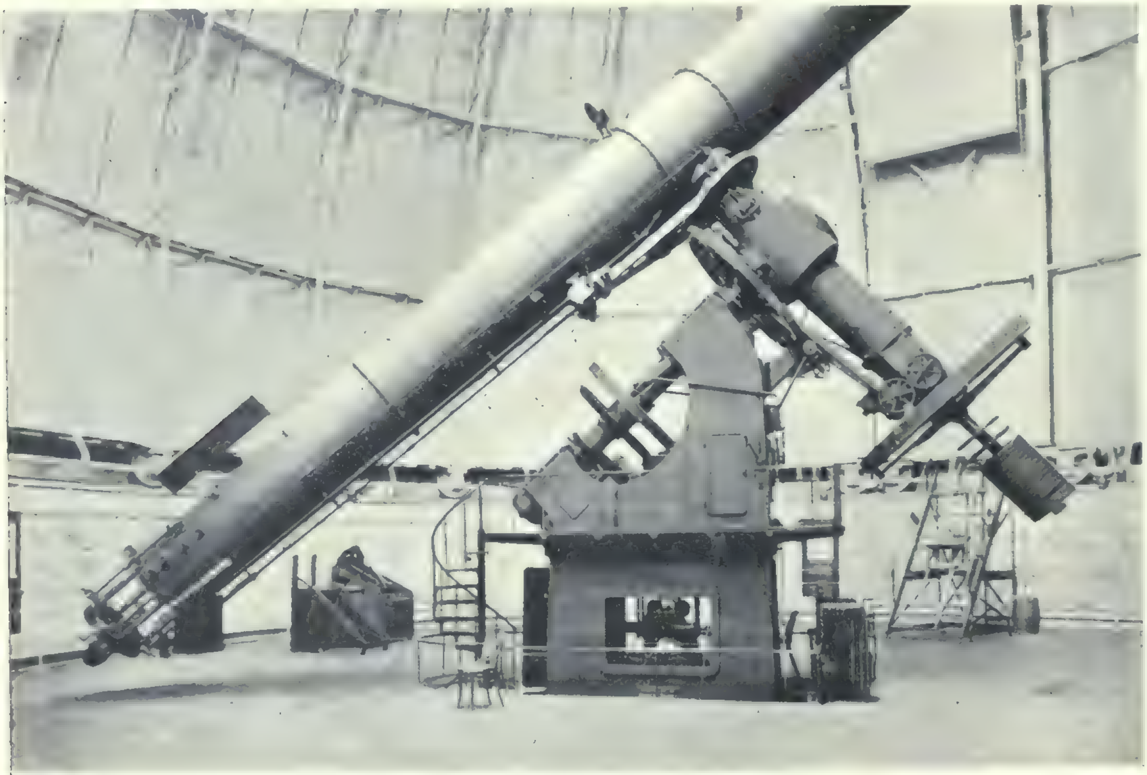


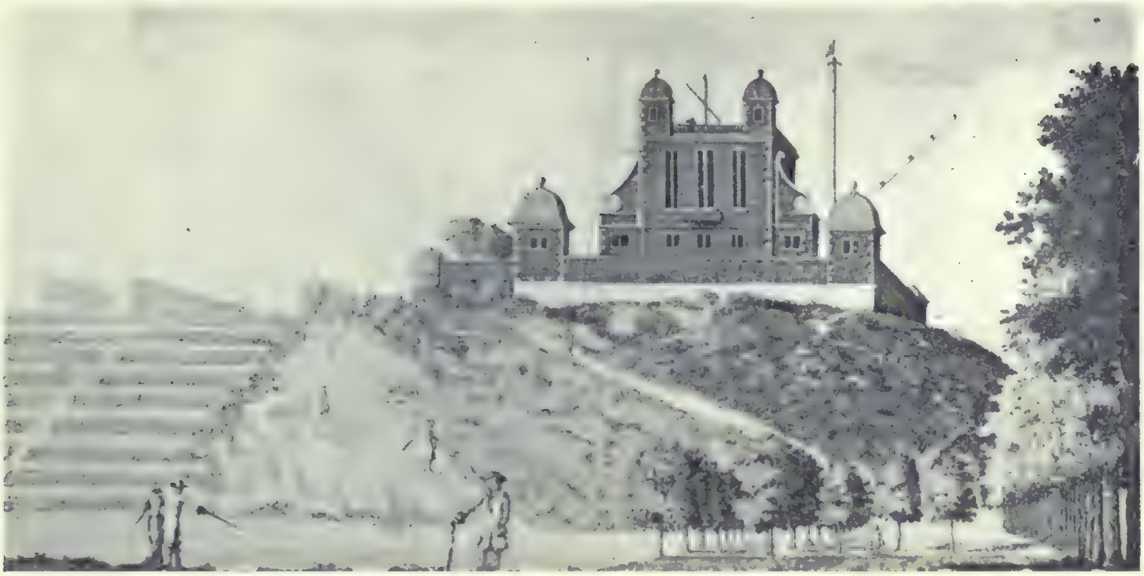
Photo by [*Yerkes Observatory.*

THE RISING FLOOR AT YERKES.

This is the largest structure of its kind in the world and is used in connection with the forty-inch refractor. Nearly eighty feet in diameter and weighing 37½ tons, it is actuated by powerful mechanism under the control of the observer. This illustration shows the floor raised to its maximum height, reaching nearly to the top of the great steel pedestal of the mounting. The photograph on page 41 gives a view of the floor in its lowest position, exposing nearly the whole of the pedestal.

in the welfare of pure science might do worse than consider the condition of some of our poorer observatories.

The inclinations of the director and his staff have naturally an important bearing on the character of the work of an observatory. Of course, in a State observatory there is always a considerable amount of routine work whose character is determined by tradition and necessity; but in all other observatories the director has practically a free hand. This is as it should be, for good results are most likely to be obtained from work which commands the genuine interest and enthusiasm of those who do it. Thus it sometimes happens that a change in the staff of an observatory brings about a corresponding change in its programme of work. Then, too, the development of Astronomy brings with it new lines, new methods, and new instruments of research, and a progressive director will, as far as possible, adapt his programme and equipment to meet them.



GREENWICH OBSERVATORY IN FLAMSTEED'S TIME.

The original buildings of Greenwich Observatory, erected by order of Charles II in 1675–76, were designed by Sir Christopher Wren. The Observatory was founded for the purpose of studying the motion of the Moon and the positions of the fixed stars, as an aid to navigation. Flamsteed was appointed first Astronomer Royal, at a yearly salary of one hundred pounds, out of which he was expected to provide himself with the instruments necessary for the observations required.

Observatories of the types so far considered are generally referred to as "public," but perhaps it is well to point out that this means no more than that they are not owned or controlled by private individuals. Members of the general public who are interested in scientific matters are apt to be

GREENWICH OBSERVATORY TO-DAY.

Since the time of Flamsteed the Observatory has undergone very considerable extensions, both in its structure and in the scope of its work. At the northern edge of the hill, on the right, Wren's building still stands, the expansion of the Observatory having taken place mainly in a southerly direction. In comparing this view with the old one, it is interesting to note that the same footpath still exists, and also even some traces of the terraces to the left of the picture.

disappointed to find that they are debarred from "having a look" through the telescopes of our large observatories, especially those to whose support the taxpayer contributes. Such disappointment is very natural, but a glance at the other side of the question will show that no real grievance is involved. A large observatory exists for the purpose of serious scientific research by qualified workers and is not intended to be a public peep-show. The admission of all and sundry for the purpose of "seeing the sights" of the heavens would involve not only the cessation of regular work with one or more of the telescopes, but also, what is even more to be avoided, the diversion of members of the staff from more important occupations; for, where delicate and complicated instruments are concerned, expert supervision and demonstration would be absolutely necessary. The same thing applies, to some extent, to the mere daylight inspection of the interior of an observatory, especially by large numbers of persons at one time, for a single touch by an unskilled hand may give much trouble by disturbing the adjustments of certain instruments, or may even cause permanent damage. The setting aside of a special telescope, complete with "showman," for the use of the public, would no doubt meet the difficulty, but few observatories are so well endowed as to be able even to think of such a thing. However, notwithstanding what has here been written, it may be said that individual members of the public can, if they are genuinely interested, often obtain special permission to inspect the instruments of an observatory during daylight hours. For such permission written application must always be made to the director, and this provision is a wise one, since the slight personal trouble involved thereby to the applicant is some guarantee that his attitude is not merely one of idle curiosity.

There still remains the question of public facilities for actual observation.

From "The Royal Observatory," by E. W. Maunder. [*The Religious Tract Society.*

THE "NEW BUILDING" AT GREENWICH.

This, the most modern portion of Greenwich Observatory, was only erected about thirty years ago, and is situated at the south end of the grounds. It is a cruciform building, consisting mainly of offices, store-rooms, etc.; and much of the daylight, or "desk" work, is done in it. The dome which surmounts the central portion covers the large "Thompson" photographic equatorial, parts of which are illustrated on pages 54 and 395.

By permission of the Astronomer Royal. [*From "Knowledge."*

THE "SOUTH-EAST" DOME, GREENWICH.

This dome covers the twenty-eight-inch refractor, the largest visual instrument at Greenwich. It is of an unusual shape, forming more than a complete hemisphere. The "bulge" thus caused was necessitated by the mounting of a longer telescope within the same octagonal brick building that was originally designed and used for a refractor of only twelve and three-quarter inches aperture. The dome is in two halves, so that by sliding open the double shutters a section of the sky is presented that reaches from horizon to horizon.

That such facilities do really exist may be a surprise to many persons in England and elsewhere. They are not, however, nearly so commonly provided as they should be. In this matter the United States is well ahead, and quite a number of " public " observatories have been established in different parts of the country during recent years. Great Britain, however, is very poorly served in this way, and only in a very few places can persons view the heavens with a telescope as part of their civic rights. This is greatly to be regretted in a country that has produced so many astronomers of renown. That there are difficulties, largely of a financial nature, in the way there is no denying. Good telescopes are expensive things to buy (though they cost little to keep in good order), and the purchase of a suitable site and the erection of an observatory add very considerably to the bill. Even this is by no means all, for there is the cost of painting and general upkeep to consider, and last, but perhaps most important of all, the employment of an expert curator who shall always, or at stated times, be available to act as demonstrator and instructor to the enquiring visitor. Instances have occurred where well-meaning private individuals have given or bequeathed a good telescope to the municipal authorities of the town in which they lived, but their failure to provide for its future on the lines indicated above has seriously detracted from the value and usefulness of the gift. Later on a few examples of the really " public " observatory will be referred to, but as has been said, these are lamentably few and far between. As matters stand the only advice that can be offered to those who are extremely anxious to look through a good telescope at the stars is to get into touch with the nearest amateur astronomer possessed of the necessary equipment, and to request the favour of a view through his glass. It is most unlikely that such a request will be refused, for every astronomer worthy of the name is always glad within reason to share with others genuinely interested some of the delights of his own pursuit.

From " The Royal Observatory," by E. W. Maunder. [*The Religious Tract Society.*

THE THIRTY-INCH REFLECTOR AT GREENWICH.

This is a photographic instrument of short focus, mounted on the " Thompson " equatorial. It has been used principally for the photography of comets and faint satellites. With it the Eighth Satellite of Jupiter was discovered in 1908 by P. J. Melotte. Examples of its work on comets will be found among the illustrations of Chapter X. The mirror itself was made by the late Dr. A. A. Common.

This brings us to yet another kind of observatory, namely, the private establishment of the amateur. It is not perhaps generally realised that quite a considerable amount of original research work in astronomy has been and is still being carried on by non-professional observers. Naturally, the observatories of the latter are in most cases on a far more modest scale than those erected and maintained by Universities and other public bodies. The possession of considerable wealth has here and there given rise to exceptions, as in the case of the late Earl of Crawford, the late Dr. Lowell, and a few others, but the great majority of amateurs have to be content with a very modest equipment, more often than not consisting of a single small instrument mounted without a cover in the back garden. The type of work undertaken varies, of course, with each

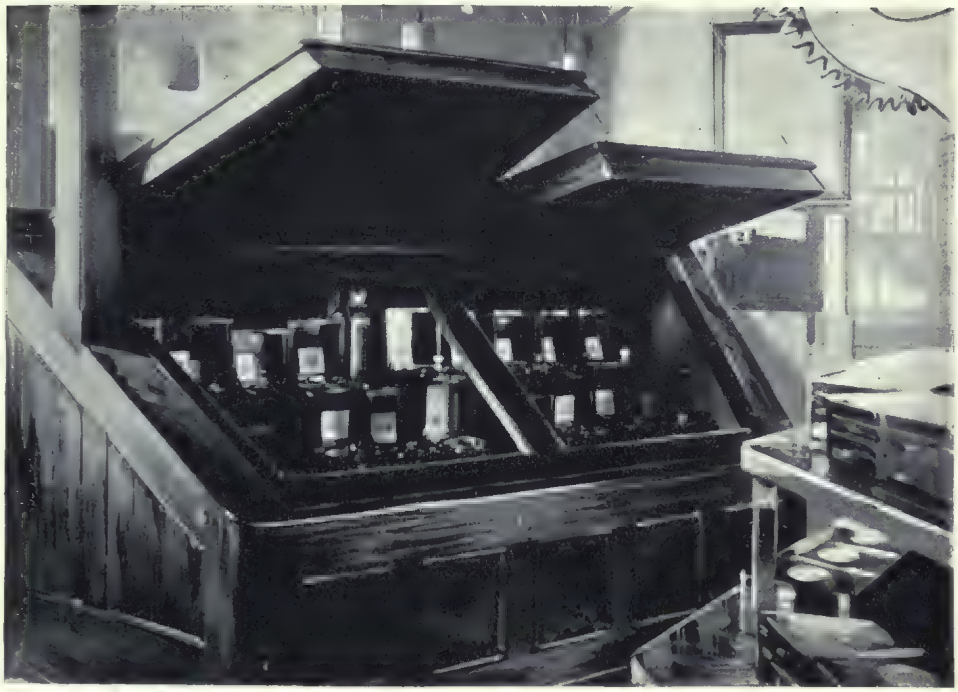
observer, but the general directions in which it usually lies have been sufficiently described in Chapter XX. It will have been noted that there is but little overlapping with the work of the public observatories, the general tendency being to concentrate on observations that do not demand the use of large and costly apparatus of great precision, or the expenditure of an excessive amount of time. The latter is of some importance, where, as generally happens, the observer is already fully occupied with business or profession during the day.

Several English public schools possess observatories, or at least telescopes, of some sort, intended for instructional purposes. They are usually under the technical control of one of the science masters, and it may be said in general that their usefulness largely depends on the enterprise and enthusiasm of this individual. Boys, if sufficiently encouraged, take readily enough to the practical study of astronomy, and in some schools full advantage is taken of the facilities provided. In others, unhappily, the reverse is the case, owing generally to lack of interest on the part of those in authority, and the mere presentation of a telescope to a school will not guarantee its use. A boy recently informed the writer that he was quite unaware of the very existence of the finely-equipped observatory possessed by the public school at which he had spent many years! Apparently no one on the staff cared a bit about astronomy and so no efforts were made to arouse the interest of the boys. The tragic part of the matter is that disuse leads inevitably to decay, and no doubt one of these days, when a science master is appointed who has a taste for astronomy, he will find the telescope and observatory

By permission of the Astronomer Royal *From "Knowledge."*

THE GREENWICH TWENTY-EIGHT-INCH TELESCOPE.

This is the largest refractor in the British Empire. It is carried by a mounting that was designed by Airy for an instrument of less than half its aperture and is driven by a water-turbine. The object-glass is capable of being adapted for photographic work, and at one time the telescope was fitted with a spectroscope. It is now, however, used almost entirely for the visual measurement of close double stars.



From "The Royal Observatory," by E. W. Maunder *The Religious Tract Society.*

THE CHRONOMETER OVEN AT GREENWICH.

The testing of marine chronometers has for long been an important feature of the work of the Royal Observatory. It is essential that the compensation of these instruments should be equal to the great changes of temperature to which they may be subjected during long voyages through various latitudes. For this reason part of their testing is carried out in artificially heated ovens of the incubator type. A refrigerator is also available for the same purpose.

quite unfit for use.

Reverting now to observatory work, both professional and amateur, it may be asked to what extent it is organised and co-ordinated, and how its results are made available for correlation in the interests of the science as a whole.

A century or so ago the condition of affairs from this point of view was a lamentable one. Plenty of good work was being done, but in "water-tight" compartments. Each observatory worked in almost complete isolation and independence, and there was little or no attempt to co-ordinate researches or to make possible the public discussion of results. This was a definite bar to progress, much valuable time being wasted on the useless duplication of various pieces of work, while investigators were hampered by their ignorance of important results obtained at other observatories. Fortunately, matters are very different to-day. For one thing, the great importance of the regular publication of results is now generally realised and a continuous exchange of these records takes place between all the more important observatories. Then again, the interchange of views is facilitated by the existence of many astronomical societies, where papers on various subjects are read, discussed, and published. The existence of such societies is especially valuable to amateurs (who, as a rule, greatly outnumber the professional members) for it secures the publication of their work, which they would in most cases find impossible at their own expense. Then there are various periodicals devoted either partly or wholly to astronomy, and these contain accounts of special researches, reports of meetings, reviews of publications, and current scientific news of general interest to the astronomer. All this helps to keep him up-to-date, and well informed as to the activities of others, and the general progress of the science. The rapid circulation of urgent items of astronomical news, such as the discovery of new stars or comets, is secured by the issue, to subscribers all over the world, of telegrams from a central bureau at Copenhagen. This system has proved most valuable in operation, for it ensures early and widespread observations of temporary phenomena, and minimises the risk of failure attributable to cloudy weather.

Quite recently there has come into existence an organisation which should prove of great value to astronomers in the future. It is known as the International Astronomical Union, and, as its name implies, is a composite body representing the interests of many different countries. Each nation

From "The Royal Observatory," by E. W. Maunder] [*The Religious Tract Society.*

THE COURTYARD, GREENWICH OBSERVATORY.

In the foreground, just to the left of the centre, is the building (with white vertical shutter) which contains the Transit Circle. To the right of this is the older Transit Room of Bradley, now used for the testing of chronometers. On a higher level two domes are to be seen. The nearer, and smaller, covers the little Sheepshanks equatorial of six and three-quarter inches aperture, the largest refractor in the Observatory up to 1850. Behind it is the great dome of the twenty-eight-inch equatorial.

is represented by some of its more prominent astronomers, and general meetings are held every three years in various important centres in different parts of the world. Broadly speaking, the aims of the Union are the co-ordination of research and the securing of co-operation among observers in the best interests of astronomy as a whole. To this end special committees are appointed to deal with each of the principal branches of work, such as the observation of the Sun, Variable Stars, Nebulæ, etc. Each committee is under an expert chairman, whose triennial report on work accomplished serves as a basis for correlation and shows in what directions further investigations are required. The Union also acts as a useful medium for the international standardisation of astronomical measurements and nomenclature; and last, but not least important, it has the control of certain funds for use in aid of research.

Before proceeding to the description of particular examples, something may be said regarding the general structure of an astronomical observatory, the following remarks applying more specially to the large public institutions. Speaking generally, the buildings of an observatory are of two kinds, depending on the nature of the work carried on in each. First come the buildings which justify the name given to the whole collection, namely, those in which actual observations of the heavenly bodies are made. These are usually constructed substantially of brick or stone, and may either be incorporated in the main body of the observatory or distributed as separate units in different parts of the grounds, the latter being now the more common arrangement. In either case one of the most important points to be considered is the stability of the foundation on which the actual instrument stands. Powerful and delicately adjusted telescopes must be secured as far as possible from the effects of vibration if they are to perform in a satisfactory way, and it would be impracticable, quite apart from their weight, to mount them on wooden floors; for, if this were done, not only would the adjustments be constantly liable to derangement, but the instrument would quiver perceptibly in response to every movement of the observer or even of persons in other parts of the building. Therefore it is necessary to provide a firm base in actual connection with the ground itself. Such a base is usually constructed of brick, stone, or granite, starting well below the general level of the ground, and carried up to the desired height. In the case of telescopes mounted at the top of buildings, this involves the erection of a massive pillar passing up through the several floors without being allowed actually to touch any of them. Also the floor of the observing room itself must be

cut away sufficiently to avoid contact with the pillar. Now comes the question of the roof or covering of the observatory, for it need hardly be pointed out that in practically all climates delicate instruments require a covering of some sort, at least when not in use. But it must also obviously be of such a kind as to allow of being opened to the sky when observations are to be made; and here it may be remarked that what is to be aimed at is the maximum degree of possible exposure that is consistent with the protection of the telescope and observer from excess of wind and dew during work.

It is no part of the functions of an observatory roof to raise the temperature within to a "comfortable" level, for experience has shown that telescopes perform best when the least possible difference exists between inside and outside temperatures, and the observer must clothe himself accordingly. As to its construction, the roof takes, in general, one of two forms. Where it covers a transit instrument a series of straight shutters (arranged in one line on north and south walls and overhead) is all that is required in the way of an opening, since the telescope can only be pointed to objects on the meridian. Any sort of roof that allows of this, generally of wood, will suffice, so that its construction may be simple and inexpensive. However, the majority of astronomical instruments are so mounted as to be available for the study of objects in all, or nearly all, parts of the sky. For these a single shutter in a fixed position would obviously be insufficient; indeed, a large number of separate shutters would be almost equally bad, since the necessary divisions and supports between them would be constantly interrupting observations of the stars as they are carried steadily across the sky by the rotation of the Earth. The difficulty is got over by making the whole roof revolve in one piece on rollers or cannon balls, which revolve on a circular rail or trough fixed to the walls of the observatory. Of course, with such an arrangement only one opening is needed, though it must be a long one, reaching from the base of the revolving roof up to or, preferably, rather beyond the zenith. Provided that its base is circular, such a roof may be of almost any shape. In the earlier days of observatories it often took the form of a wooden "drum," as this is a shape that is easy of construction, though neither ornamental nor economical in the matter of material required. Nowadays, however, a more or less hemispherical form of roof is nearly always adopted and the "dome" is perhaps the most characteristic feature whereby

From "The Royal Observatory," by E. W. Maunder [*The Religious Tract Society.*

THE ROYAL OBSERVATORY, GREENWICH.

This illustration gives a view of the more modern portions of the Observatory, as seen from Wren's original structure. In the distance is the Thompson dome, on the New Building. Low down among the trees is the Altazimuth dome. Nearer still are successively the domes covering the twenty-eight-inch refractor, the little "Sheepshanks" equatorial, and the Astrographic telescope. The white vertical shutter, at the left of the nearest block, belongs to the room containing the transit-circle, and marks the meridian of Greenwich, or longitude 0°.

an observatory may be recognised as such from the outside. Such domes may be made of wood, but more often consist of a skeleton framework of steel covered with metal plates or sheets of papier-maché, the latter to minimise the weight. A system of geared wheels, often worked by an endless rope, is provided on the inside for the rotation of the dome by the observer. In the case of a large dome, weighing perhaps several tons, the constant necessity of rotating it by hand entails a considerable amount of really hard manual labour on the part of the worker or an assistant ; in consequence, many modern domes are moved round by an electric motor, which greatly adds to their convenience in use. Another modern aid to comfort in observing is the rising floor, invented by Sir Howard Grubb. In the absence of this device high step-ladders or adjustable platforms on wheels have to be provided to enable the observer to reach the eye-piece in various positions of the telescope ; but, where the entire floor of the observatory can be moved up and down by hydraulic or electric power, such cumbersome pieces of furniture can be dispensed with. When about to commence work with an equatorial, the observer first of all winds up and sets in motion the clockwork driving-mechanism of the telescope. Then, with a knowledge of the sidereal time, and the right ascension and declination of the object to be studied, he points the telescope in the desired direction by means of the divided circles attached to the mounting and puts the clockwork in gear with the polar axis. The next thing to do is to rotate the dome until the shutter is brought opposite to the object-glass ; and, last of all, the shutter is opened and all is ready for the observer to take his place at the eye-piece.

The above remarks with regard to housing and manipulation apply chiefly to telescopes of the orthodox equatorial form, but it should be noted that for instruments of special design (*e.g.*, Coudé, Littrow spectrograph, tower telescopes, etc.) different arrangements have to be made, and some of these will be described later on.

In addition to those buildings in which actual observations are made, there are usually others of a different kind, and hardly less important. These include offices in which computations and other kinds of " desk-work " are done during daylight hours. Generally, too, there will be a library and some rooms for the storing of photographs and written records, and, in the case of a University observatory, probably a lecture-room as well. Not the least important part of an observatory in which astrophysical work is done is a well-equipped laboratory, wherein spectroscopic and other experi-

From " The Royal Observatory," by L. W. Maunder. *The Religious Tract Society.*

THE OCTAGON ROOM IN FLAMSTEED'S TIME.

This old print gives us an idea of the use to which the octagon room was originally put. It has, however, long ceased to fulfil the functions of an observatory, its principal use being that of a meeting-room for the Board of Visitors at the Annual " Visitation," which takes place on the first Saturday in June.

mental work can be undertaken on the lines explained in Chapter XII. Finally, most large observatories are provided with a good workshop in which instruments can be adjusted, repaired, modified, or even entirely constructed independently of outside aid.

The notes which follow, giving some details of the principal equipment and work of some typical modern observatories, may serve to give the reader an idea of the methods in daily use by astronomers throughout the world in various lines of research. The order adopted, which is roughly geographical, is not necessarily an index of relative importance. Moreover, many famous observatories have had to be omitted altogether through lack of space, and the descriptions of those included are for the same reason far from complete.

From "The Royal Observatory," by E. W. Maunder [*The Religious Tract Society.*

FLAMSTEED HOUSE, GREENWICH.

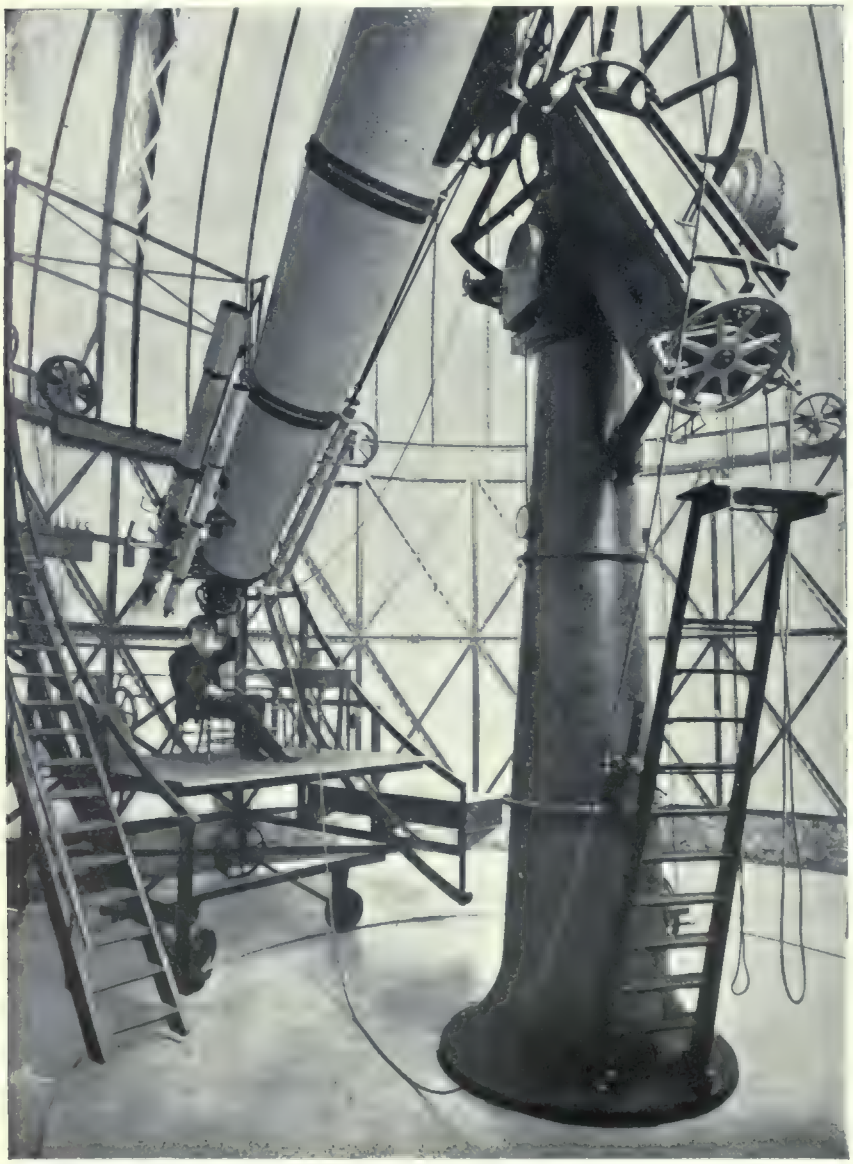
This is a view, from the courtyard, of the oldest part of the Royal Observatory. The portion here seen consists chiefly of the old "octagon room," on the roof of which are mounted the wind instruments and time-ball. On a lower level are the smaller living rooms, increased in number from time to time, which comprise the official residence of the Astronomer Royal. The whole building is appropriately named after the first holder of this title.

It is, perhaps, natural to start with the Royal Observatory, Greenwich, which for so long stood almost alone, and which is universally regarded as the prototype of the modern observatory. We have already seen how it was founded, in the first instance, for the sole purpose of "perfecting the art of navigation"; and this purpose, steadily kept in view since its foundation, is still the primary object of the observatory. It is true that the great increase in the speed of ships and the advent of wireless telegraphy have made the navigator much less dependent on the astronomer than was the case two, or even one, hundred years ago; but the Nautical Almanac is still a necessary part of the equipment of every ocean-going vessel, and the positions of heavenly bodies set down therein depend on observations made regularly at Greenwich. Navigation is further aided at the observatory by the testing of marine chronometers and by systematic study of terrestrial magnetism.

The most important instrument at Greenwich, at any rate from a utilitarian point of view, is the eight-inch transit-circle, with which the positions of the Sun, Moon and "clock-stars" are determined for the Nautical Almanac, and with which time is obtained for distribution, as explained in Chapter XIX, where the instrument has already been sufficiently described. It may here be noted that the observations made with it are a good deal more precise than is necessary for purposes of navigation, and they provide the material for standard catalogues which are of the greatest value for various purposes of exact astronomy. In the case of observations of the Moon (for position) the transit-circle is supplemented by a somewhat similar instrument of the same aperture, the altazimuth, so called because it is capable of movement in azimuth, or horizontally, as well as in altitude, or vertically. By its means the crescent moon, which can only be observed in daylight (and therefore inconveniently) with the transit-circle, can be dealt with in a dark sky when far removed from the meridian. These two instruments, the transit-circle and the altazimuth, are the only two that can be said to have a direct connexion with navigation, and they represent the traditional part of the work of the Observatory.

In the course of time, however, and more especially during the past forty years, the equipment has been greatly increased in several directions and many branches of work are now undertaken with objects that are less severely practical than the finding of the "so-much-desired longitude at sea."

Several domes, small and large, in different parts of the Observatory, bear witness to these extensions of its activities. At the extreme south end of the grounds is a large cruciform building, consisting chiefly of large rooms devoted to "desk-work," storage, and similar purposes, but surmounted centrally by a dome which covers what is, in the matter of size and efficiency, the most important instrument at Greenwich. This is the Thompson Equatorial, a composite instrument consisting of several different telescopes attached to the same mounting. One end of the declination axis carries a twenty-six-inch photographic refractor, which is used principally for the determination of stellar parallaxes (*see* illustration on page 54). Attached to this is a visual refractor of twelve and three-quarter inches aperture, formerly mounted alone in another dome, but now used as a "guiding-telescope" for the twenty-six-inch. A nine-inch photographic refractor for solar work was also for many years mounted on the opposite side of the tube of the parallax telescope. At the other end of the declination axis, and acting as a counterpoise to the three instruments already mentioned, is a thirty-inch photographic reflector, of short focus. This is used for various purposes, including the photography of comets and faint satellites. By its means the Eighth Satellite of Jupiter was discovered by P. J. Melotte in 1908. A spectrograph is attached to



From "Star-gazing", *By Lockyer.*

THE NEWALL TELESCOPE, CAMBRIDGE.

This great instrument, of twenty-five inches aperture, was originally constructed for the late Mr. R. S. Newall, an amateur of Gateshead, in 1868. It was then the largest refractor in the world. Later it was presented by its owner to the University Observatory at Cambridge, where it is now used for photographing stellar spectra. It is some time since any visual observations were made with it.

this instrument; but stellar and solar spectroscopy, at one time an item in the Greenwich programme, are no longer part of the regular work of the Observatory.

Proceeding northwards from the direction of the New Building, and passing on the way the small isolated dome covering the Altazimuth, we come to the older portions of the Observatory, situated at the northern end of the grounds. At the southern end of the block is a three-storeyed octagonal brick building, surmounted by a large dome shaped somewhat like a "puff-ball"; that is, it forms more than half of a sphere. This covers a refractor of twenty-eight inches aperture, the largest in the British Empire. The telescope, which is fixed to the mounting that formerly carried the twelve and three-quarter inch refractor already mentioned, is capable of being used either as a visual or photographic instrument by suitable adjustment of the object-glass, and at one time a large spectroscope was attached to it. Now, however, it is used almost exclusively for the visual measurement of close double stars, a work for which its great aperture makes it eminently suitable. Farther on in the same block of buildings we come to the room in which the transit-circle is mounted; and after that, to the office that is the centre of the time department, with the room for the testing of chronometers leading out of it. Beyond this, and on a higher level, is mounted the astrographic equatorial, which is of the standard type illustrated on page 50. Greenwich was one of the eighteen observatories that undertook, in 1887, to share the charting of the entire heavens by means of photography. The "zone" allotted to it was finished many years ago, and the telescope is being used now for the retaking of a certain proportion of the areas previously photographed. The comparison of old and new plates, taken with the same instrument, makes possible the accurate measurement of proper motions. With this instrument and the photographic telescopes of the Thompson equatorial, photometric investigations have been made in recent years in connexion with the standardisation of photographic magnitudes, the method used being that illustrated on page 589. Not far from the Astrographic dome is the small drum-like structure which covers the photoheliograph, illustrated on page 64. With this little four-inch telescope, whose aperture is generally cut down to about three inches, the Sun is photographed on every fine day at Greenwich, the scale being eight inches to the solar diameter. The uses to which these photographs are put have been described in Chapter III.

By permission of [*The "Observatory Magazine."*

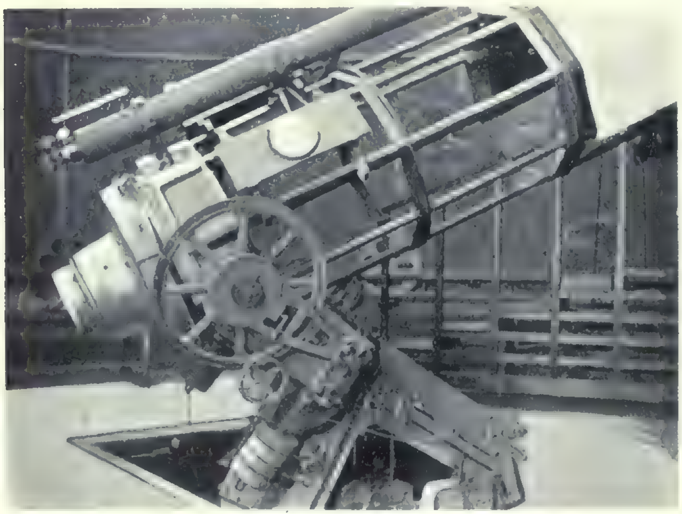
SIR DAVID GILL (1843–1913).

Gill was one of the most skilful and accurate observers of modern times. Working with comparatively small instruments, he attained a high standard of precision in his measurement of the parallaxes of Sun and stars. During his twenty-seven years' directorship of the Cape Observatory, he devoted much attention to exact meridian and geodetic work, and he was one of the pioneers of stellar photographic cartography.

One more astronomical instrument in regular use at Greenwich is worthy of mention. It is known as the Cookson floating zenith telescope, after the name of its designer, and is on loan to the Observatory from Cambridge. Of only six inches aperture and less than six feet long, it would appear at first sight incapable of refined work, but this is far from being the case. The telescope, which

rotates, by flotation in a circular trough of mercury, about a vertical axis, is used for photographing stars which pass nearly through the zenith. The apparent position of the latter point on the star-sphere is determined with great accuracy by measurement of the photographs, and hence is deduced the minute periodic change in the latitude of Greenwich, and other places, caused by the slight shift of the direction of the Earth's axis within its substance. This shift is so small that at its maximum it changes the place of the north and south poles by no more than thirty-five feet from their mean positions on the Earth's surface.

The Cookson telescope is housed in a little shed in the courtyard, near to the original building of the Observatory. This building, to which additions have been made from time to time, is called Flamsteed House, after the first of the Astronomers Royal, whose official residence is incorporated therein. The time-ball, referred to in Chapter XIX, is mounted on a turret at the top of the oldest, or northern, portion of the building, which is the part erected by Wren in 1675. This portion contains the Octagon room, from the windows of which observations were made in the very early days of the Observatory.



[E.N.A.

THE THIRTY-INCH REFLECTOR AT HELWÂN.

This short-focus photographic reflector, presented to the Helwân Observatory by Mr. J. H. Reynolds, has been used chiefly for the photography of nebulæ that are too far south to be visible or easily studied in higher latitudes. Several of the photographs illustrating Chapter XIV were taken with it. The original mirror of the telescope was made by the late Dr. Common, but the one now in use is by G. W. Ritchey, who figured the sixty- and hundred-inch mirrors at Mount Wilson.

This brief description will have served to give the reader some outline of the chief activities of Greenwich, which is a typical State observatory, devoted mainly to the astronomy of position. There are several other important observatories in the British Isles. That of Cambridge is one of the largest and possesses features of special interest. Actually there are two observatories, the "University" and the "Solar Physics," but both are situated in the same grounds, about a mile out of the town, and may conveniently be described together as if they formed one institution. The University Observatory possesses a fine eight-inch transit-circle which has been used for obtaining accurate positions of certain stars for catalogue purposes. It is housed in the main building, which was erected in 1824. In a separate building in the grounds is an historic instrument, the Northumberland refractor, of eleven and a half inches aperture. This was the telescope with which Challis searched for Neptune in 1846 at the instigation of Adams and Airy, as described in Chapter IX. The mounting and dome are somewhat antiquated, and the instrument is now only used for exhibiting the more striking celestial objects to members of the University on fine Saturday nights. In another part of the grounds is mounted the Sheepshanks equatorial, illustrated on page 455. As will there be seen, it is of a modified "coudé," or elbowed, form; the rays from the twelve-inch object-glass being reflected up the tube (which also forms the polar axis) by means of a plane silvered mirror. The advantage of this is that the eye-piece of the telescope remains stationary, except for rotation, and the observer is more sheltered than in an ordinary observatory. The telescope is available either for visual or photographic work, but has chiefly been used for the latter. Probably its best work has been the photographing of the minor planet Eros, in 1899-1900, by A. R. Hinks, who used the plates thus obtained for his determination of the solar parallax.

One of the largest refractors in the Kingdom is mounted at Cambridge. This is an instrument of twenty-five inches aperture, made in 1869 for an amateur, Mr. R. S. Newall, of Gateshead, and later presented by him to the Observatory. At the time of its construction it was the largest telescope of its kind in the world. It was primarily intended for use as a visual instrument, but is now used, in conjunction with a correcting lens and powerful spectrograph, for the photography of stellar spectra. While actually belonging to the University establishment, the Newall telescope is now, so far as its work is concerned, regarded as part of the equipment of the Solar Physics Observatory. The latter institution was originally established at South Kensington, where it was directed by the late Sir Norman Lockyer, but it was removed to Cambridge in 1913. As its name implies, it is principally devoted to work on the Sun, and it is one of the very few observatories in Great Britain in which any kind of solar research is undertaken. The chief instrument in regular use is a large spectroheliograph, working on the general principle described and illustrated on page 66. In the case of the Cambridge apparatus the object-glass, of twelve inches aperture, is mounted in a fixed position and the Sun's rays pass through it in a horizontal direction, being reflected into it by a large plane mirror mounted equatorially and driven by clockwork. This is a device frequently adopted for long and cumbersome instruments, which can be mounted more cheaply and rigidly in a fixed position. The rotating mirror, which is a comparatively small and inexpensive piece of apparatus, is known as a "siderostat," or "coelostat," according to the particular manner of its mounting. The one at Cambridge is a siderostat. The spectroheliograph is used for photographing the Hydrogen and Calcium layers of the solar atmosphere, as described in Chapter IV. The English climate is not very favourable for this kind of work, but advantage is taken of every available opportunity. A laboratory for parallel study of terrestrial spectra is attached to the Observatory.

By kind permission of [*J. Evershed.*

THE KODAIKANAL OBSERVATORY, MADRAS.

Situated about 7,700 feet above sea-level, this is one of the highest observatories in the world. It is devoted almost entirely to the study of solar physics. Special attention has been given to measurements of the velocity of currents at different levels in the Sun's atmosphere, as revealed by spectrograms taken under high dispersion. In the course of this work the minute shift in the lines of the solar spectrum, predicted by Einstein, has been definitely detected.

In the years during which the Solar Physics Observatory was situated at South Kensington, stellar spectroscopy formed a considerable portion of its programme. On his retirement from the directorship of the Observatory, the late Sir Norman Lockyer, who felt keenly that the work should be continued, determined to found a new observatory for the purpose. This he did, with the aid of certain friends, and the establishment was erected at Sidmouth; later to be incorporated under the title of the Norman Lockyer Observatory. It is considered worthy of special mention here as being the only observatory in the British Isles that is almost wholly devoted to astrophysical work. The equipment is a modest one as compared with that of some American and Continental observatories, but valuable results have been obtained by following those lines of work that are well within the compass of the instruments. At the present time (1923) the activities of the Observatory are principally directed towards the determination of spectroscopic parallaxes, following the method originated by W. S. Adams, of Mount Wilson. This method has been described in Chapter XI, and the results obtained at Sidmouth have demonstrated the possibilities of the objective-prism in work of this kind.

[E.N.A.

THE SEVENTY-TWO-INCH TELESCOPE AT VICTORIA, B.C.

This telescope, erected recently at the Dominion Astrophysical Observatory, Victoria, is the largest in the British Empire. It is used chiefly for the determination of the radial velocities of stars by means of the spectrograph attached to its lower end. The weight of the moving parts is very considerable, but the telescope can be readily moved into any desired position by means of electric motors of variable gearing. The system whereby the observing platform is attached to the shutter of the dome will be noted.

A general view of the Norman Lockyer Observatory will be found on page 499, and one of the instruments is illustrated on page 507.

A few more observatories in different parts of the British Empire are worthy of mention before we pass on to foreign establishments. One of the oldest is the Royal Observatory at the Cape of Good Hope. This is a State Observatory and is, like that of Greenwich, under the control of the British Admiralty ; in fact, it may almost be regarded as the Southern Hemisphere branch of the older institution. Its work, too, is on somewhat similar lines, though its staff and equipment are on a smaller scale. Accurate meridian work has for long been a great feature of the routine, and the transit-circle is one of the finest in the world. For some years the Observatory was engaged in taking its share in the construction of the Astrographic Chart. The zone allotted to it has long been completed, but the standard instrument, similar to that at Greenwich, is still available for photographic work involving the measurement of stellar positions and magnitudes. The largest instrument in the Observatory is the twenty-four-inch Victoria telescope, a photographic refractor very similar in type and mounting to the Thompson refractor at Greenwich. It has been used for direct photography of satellites (for position) and of certain southern celestial objects, but is now chiefly employed, in conjunction with a spectrograph, for the determination of radial velocities. The Sun is photographed daily at the Cape with an instrument similar to the little Greenwich photoheliograph. The object of this work is to fill in the inevitable gaps caused by cloudy weather at the Northern Observatory. The plates which fill these gaps are sent to Greenwich for measurement and filing at the end of each year. Other branches of work at the Cape include the maintenance of the local time-service and the keeping of meteorological and seismographic records.

At the opposite end of the African continent is an observatory which should be of special interest to readers of this work. It is situated on the Mokhattam Hills, at Helwân, overlooking the Nile a few miles south of Cairo. The chief astronomical instrument of the Observatory (which also undertakes meteorological and seismographic work) is a thirty-inch photographic reflector, made and presented by Mr. J. H. Reynolds, of Birmingham. It has done splendid work in the photography of many southern nebulæ and clusters that had never before been adequately studied by such means. Several

of the illustrations in Chapter XIV are from photographs taken with this instrument, which was also the first to photograph Halley's Comet in 1909. Later, a fine series of plates was taken in 1910, when the Comet was at its nearest to Earth and Sun ; and the telescope has also been used to photograph the Eighth Satellite of Jupiter when the planet was placed too low in the sky for successful work at Greenwich.

There are a few observatories in India. One is of special interest as being by far the highest in the British Empire. It is situated at Kodaikanal, 7,745 feet above sea-level, and is a branch of the old Madras Observatory. It is devoted almost entirely to the study of Solar Physics, for which its position makes it specially suitable. Much of our present knowledge of the Hydrogen and other layers of the Sun's atmosphere is due to the work done here with a spectrograph and spectroheliograph by J. Evershed, who in 1918 was awarded the gold medal of the Royal Astronomical Society in recognition of his researches in this field. Particular attention has been given to the accurate measurement of line-of-sight, or radial velocities exhibited by the solar gases at different levels and in different parts of the disc. This work is done by measuring the positions of the lines in spectra taken under high dispersion, and the interpretation of the results is a matter of considerable difficulty, for many different factors, known and unknown, combine to produce the displacements observed, and each must be separately dealt with. In view of these difficulties it is gratifying that Mr. Evershed is able to state with some confidence that he has been able to isolate definitely the minute shift in the lines required by Einstein's theory (*see* illustration on page 684). Hitherto this theoretical displacement has defied

[*U.P.S.*

THE PARIS OBSERVATORY.

This is the National Observatory of France, corresponding in its functions to the similar institution at Greenwich, which was founded at about the same time. In the background is the original building of the Observatory, carrying several more modern instruments on its solid stone roof. One of the small domes in the foreground covers the original "astrographic" telescope, designed and constructed by the brothers Henry.

ASTROGRAPHIC TELESCOPE OF THE PARIS OBSERVATORY.

Experiments in stellar photography, made in the early 'eighties by the brothers Henry with this telescope, led to the adoption of the latter as a model for the instruments to be used in constructing the great Astrographic Chart of the Heavens. The photographic lens and plate are, in this original model, mounted in the same tube with the visual guiding telescope. The equatorial mounting is of the "English" type.

practical demonstration owing to the much larger shifts due to other causes. The case is somewhat similar to that of the lunar tide in our atmosphere as shown by its effect on the barometer. The much grosser changes attributable to local effects so effectually masked this minute tide that it remained undemonstrated until quite recently. Some photographs obtained by Mr. Evershed with the spectroheliograph at Kodaikanal will be found in Chapters III and IV. Direct pictures of the Sun's disc are also taken on every fine day and duplicates of many of these are, like those taken at the Cape, sent to Greenwich to fill the gaps in the collection.

To Canada belongs the distinction of possessing the largest telescope in the British Empire. This is the six-foot reflector recently erected near Victoria, British Columbia, which station forms a branch of the older Dominion Observatory at Ottawa. With one exception the telescope is the most powerful in the world, and already a great amount of valuable work has been done with it. As is usual with large modern instruments, it is used principally in investigations for which its great light-grasp renders it specially suitable. At present it is devoted mainly to the determination of the radial velocities of stars that are too faint to be dealt with adequately by smaller instruments. The construction of the fine spectrograph attached to the telescope (illustrated on page 496) makes it possible to vary the dispersion (that is the length of the spectrum formed) at will, according to the requirements of the particular work being done. In the course of this study of the general motion of the stars selected for observation many spectroscopic binaries and some eclipsing variables have been brought to light, and the orbits of several of these have been investigated by measurements of the variable velocities revealed by the shifting of the spectral lines. For such work high dispersion is, of course, essential, and this would mean very prolonged exposures in the case of all but the brightest stars if a very large instrument were not available. The six-foot

reflector is available for direct photography, if required, and the beautiful picture on page 533 is an example of its work when so used. Very little visual work is done with this or any other large reflector, but it is readily adaptable for this purpose when occasion requires, and is in fact regularly so arranged for demonstration of the principal sights of the heavens to the general public on Saturday evenings.

Turning now to observatories situated on the continent of Europe, that of Paris is a natural starting-point, since, as we have seen, it was one of the first to be established (towards the end of the Seventeenth Century) on what may be called modern lines. It is a State observatory, and is to France what Greenwich is to Great Britain. This being so, its principal work is of a fundamental character and consists in the measurement of the exact places of standard or "clock" stars, and the determination and distribution of accurate time. These two concurrent lines of work have always been a great feature of the Paris programme, and the meridian instruments of the Observatory are among the finest in the world. To Paris belongs the distinction of having inaugurated the system of time-distribution by means of wireless telegraphy. In this the Observatory is assisted by the proximity of the great aerial attached to the Eiffel Tower, being connected to the wireless station there by means of a land-line. Thus at definite times the standard mean-time clock can be put into direct touch with the transmitting apparatus, and itself actuates the relay which sends the signal into the aerial.

[U.P.S.

COUDÉ EQUATORIAL, PARIS OBSERVATORY.

With this form of telescope the observer sits stationary within the building, looking down the inclined tube of the instrument, which also forms its polar axis. The object-glass is at the upper end of the second part of the tube, which is set at right angles to the first. A plane mirror at the "elbow" sends the rays from the object-glass through this angle, and a similar mirror mounted in a rotating box over the object-glass serves to set the telescope in Declination. The Paris Coudé has an aperture of 23·6 inches, and was used for the construction of a photographic atlas of the Moon.

As was the case with Greenwich, the French National Observatory has from time to time undergone expansions of its activity beyond the field of meridian Astronomy. It was here that the brothers Henry investigated the possibilities of photographic celestial cartography in the early 'eighties of last century, and we have seen in Chapter I how the type of instrument evolved by them came to be universally adopted for work on the great Astrographic Chart at the Paris Conference of 1887. The original instrument, as constructed by the brothers Henry, is still in use at the Observatory. Its mounting is of the "English" type, being similar to that adopted for the one-hundred-inch reflector at Mt. Wilson (*see* page 39), though of course on a much smaller scale. Another of the Paris instruments, of unusual design, owes its origin and development to the genius of the Henrys. This is the great equatorial coudé, of 23·6 inches aperture, illustrated on page 791. The instrument was the outcome of successful experiments made with a smaller model, of about ten inches aperture. The tube is in two portions, fixed at right angles to one another. At the "elbow" thus formed is fixed a plane mirror, set at forty-five degrees so as to reflect the rays from the object-glass up that part of the tube which forms the polar axis. The eye-piece is under cover at the upper end of this axis, and has no lateral movement. Setting in declination is effected by rotation of another plane mirror fitted in a frame in front of the object-glass. It will be noted that in the modified form of coudé at Cambridge (page 455) this second reflection is dispensed with, the declination being changed by an angular motion of the objective portion of the tube, and by simultaneous rotation of the single mirror at half the speed. Each form of the instrument has its special advantages and defects, but the coudé has never become as popular as might have been expected and few examples are to be found outside the land of its birth. However, the great Paris instrument was very successful in actual use, as will be seen by examination of its chief work, the great photographic atlas of the Moon, prepared by MM. Loewy and Puiseux. Some sections of this fine chart will be found among the illustrations of Chapter VI. An excellent model of the earlier of the two Paris coudés is to be seen at the Science Museum, South Kensington, where there is a fine collection of astronomical photographs and instruments, ancient and modern.

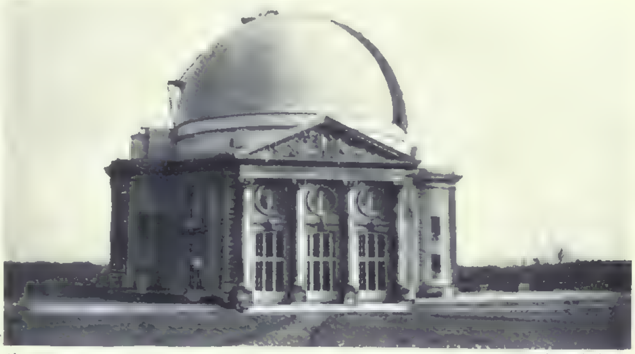
U.P.S.

M. B. BAILLAUD.

The veteran Director under whom the Paris Observatory has made important contributions to problems concerned with the determination of longitudes and the distribution of accurate time.

The equipment of the Paris Observatory includes three equatorials, of eight, twelve, and fifteen inches aperture, used for miscellaneous observations such as the measurement of double stars and the

positions of comets, etc. The largest of these is interesting as being one of the few big telescopes to be found anywhere mounted on the actual roof of a tall building, instead of on a pillar reaching up from the ground level. This is made possible only by the unusually solid construction of the old buildings of the Observatory, which are fashioned throughout of massive blocks of stone.

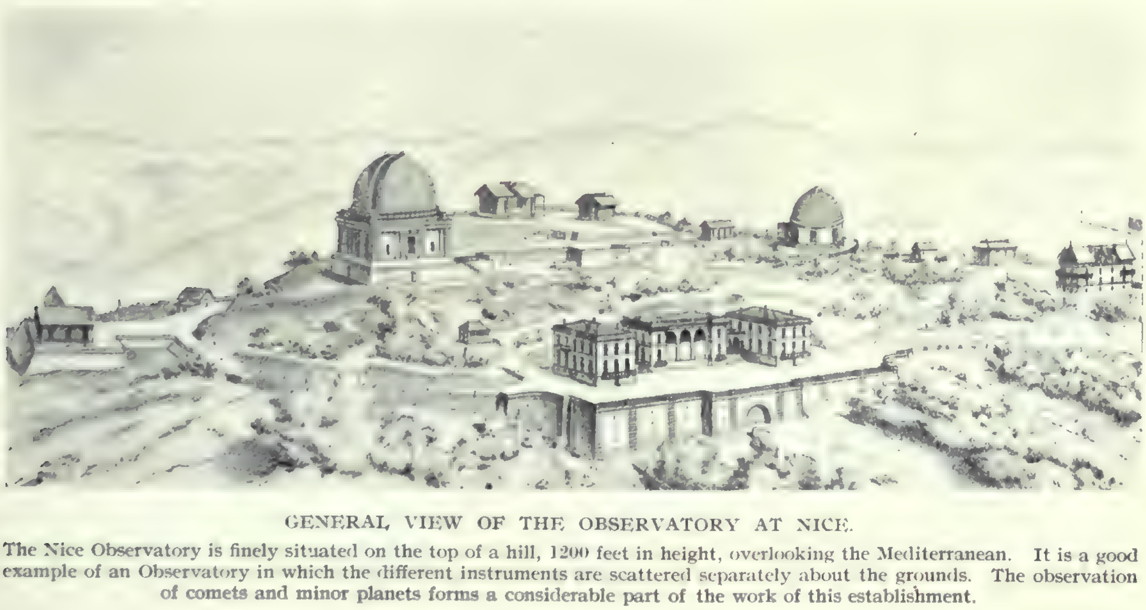


From "Knowledge."

THE MEUDON OBSERVATORY.

Situated a few miles out of Paris, the Observatory at Meudon is devoted chiefly to solar physics. Here the spectroheliograph was independently evolved by the present director, M. Deslandres. The dome here seen covers the largest refractor in Europe. The visual object-glass, 32·7 inches in diameter, is mounted in the same tube with a photographic lens of 25·2 inches aperture. Both have the same focal length of about fifty-two feet.

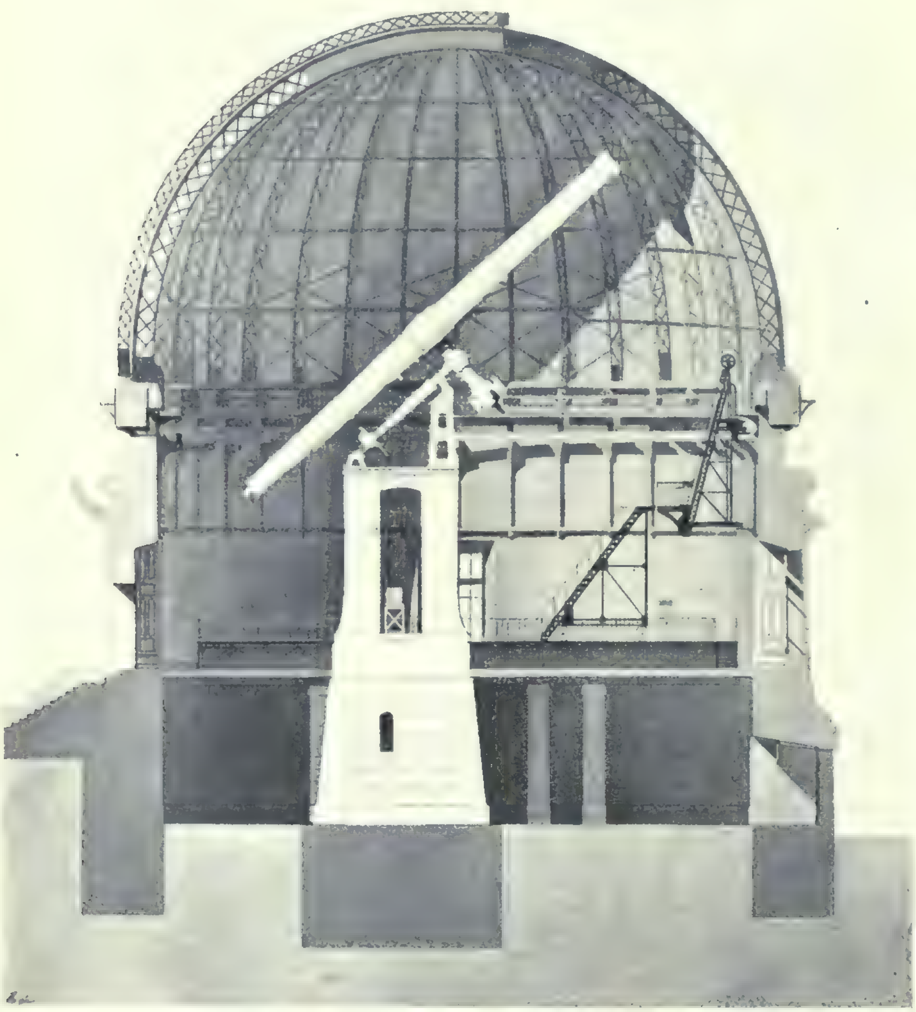
The French National Observatory is, like the corresponding institution at Greenwich, given over almost entirely to the Astronomy of position. But, a few miles away, in the suburb of Meudon, there is a fine establishment that is devoted entirely to astrophysical work. It is beautifully situated on the top of a hill, in the grounds of what was once a royal château. The most prominent external feature of the Observatory is a large white dome, sixty feet or so in diameter. This covers the largest refracting telescope in Europe, whose object-glass, 32·7 inches in diameter, was made by the brothers Henry. Mounted in the same rectangular tube by the side of the great visual object-glass is a photographic lens of 25·2 inches aperture, the pair having the same focal length of rather over fifty feet. The complete instrument, as regards its moving parts, is the heaviest refracting telescope in the world, weighing about twenty tons. Among the various uses to which the visual portion has been put may be mentioned the examination of planetary detail, and the beautiful pictures on pages 77 and 351 are examples of what has been done with it in this direction. But, at any rate in recent years, the most important work of the Observatory has been done outside the large dome with instruments of a very different type. It was at Meudon, in the early 'nineties of the last century, that M. Deslandres, the present director of the Observatory, carried out the experiments that resulted in his independent invention of the spectro-



GENERAL VIEW OF THE OBSERVATORY AT NICE.

The Nice Observatory is finely situated on the top of a hill, 1200 feet in height, overlooking the Mediterranean. It is a good example of an Observatory in which the different instruments are scattered separately about the grounds. The observation of comets and minor planets forms a considerable part of the work of this establishment.

heliograph, which has contributed so largely to our knowledge of the Sun's atmosphere. Naturally, the work so splendidly begun has been continued and still further developed at Meudon, where a fine spectroheliograph, in regular use, replaces the more crude and elementary apparatus of thirty years ago. In the early days of the Observatory some particularly fine work was done by Janssen in the direct photography of the Sun's disc on a large scale. One of Janssen's photographs, showing the "rice-grain" structure of the photosphere remarkably well, is reproduced on page 119, and it is doubtful whether it has ever been surpassed in its definition and grasp of minute detail.

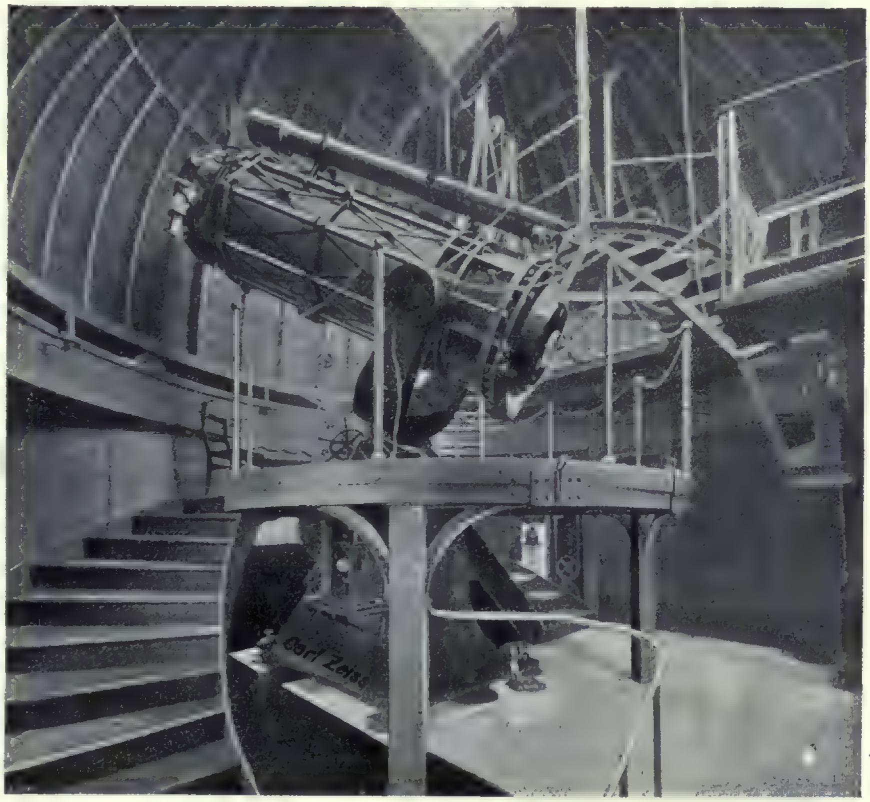


THIRTY-INCH REFRACTOR OF THE NICE OBSERVATORY.

This sectional view of the large dome, seen on the left in the previous illustration, gives some idea of the massiveness of construction necessary to give stability to the mounting of a big telescope. The bulk of the great stone pedestal and its foundation lies below the level of the floor, which is just separated from actual contact with it.

There are several more large and important observatories in France. Probably the most favourably situated is that at Nice, on the coast of the Mediterranean. The site is a very beautiful one, on the summit of a hill, 1,200 feet in height, just beyond the outskirts of the town. The white domes and buildings, scattered at intervals about the grounds, stand out sharply in the bright sunshine of the Riviera, and are visible for many miles. The largest instrument is a refractor of thirty inches aperture, whose object-glass, like that of the great Meudon telescope, was made by the brothers Henry. Early in its career it was pretty regularly used, and many drawings of Mars and Jupiter were made with it by M. Perrotin. Of late years, however, it has been used less frequently than some of the smaller instruments of the Observatory, chiefly because its great size makes it a rather cumbersome and inconvenient telescope for one or even two men to work satisfactorily, and the staff of the establishment is strictly limited. When it is remembered that the telescope is over fifty-eight feet long, and is

covered by a dome seventy-eight feet in diameter and weighing nearly 100 tons, the preference given to more manageable instruments will readily be understood. The two telescopes with which most of the work is done are equatorials of fifteen inches aperture, both being used chiefly for the visual observation and discovery of minor planets and comets. One of these equatorials is of the coudé type, and it is with this that most of the cometary work is done. Nice is one of the few large observatories in which deliberate search is made for comets, and many have been discovered at the Observatory during the past thirty years. The other equatorial is, in design, a miniature of the great thirty-inch, and is easily managed by one observer. An ingenious method has been devised whereby it can be used for the visual detection of minor planets. Near the eye-piece is mounted a box into which can be inserted glass transparencies, printed from photographs of different regions of the sky. These can be illuminated from behind by a blue light and are so arranged as to be visible with an eye-piece simultaneously with the actual stars observed with the other eye through the telescope and on the same scale. The eye-piece of the telescope is provided with a screen of yellow glass, which gives its tint to all the stars in the field. If these stars are all precisely duplicated by the images on the transparency (as they normally would be), their yellow and blue images are blended physiologically into a single whitish image. If, however, a strange object is present, either in the sky or on the plate, it reveals itself at once by its unneutralised yellow or blue colour, and in this way many new minor planets have been discovered and several lost ones redetected. Other instruments of the Observatory at Nice include a transit-circle of unusually massive construction, used for determining the positions of stars for catalogue purposes.



TWENTY-EIGHT-INCH REFLECTOR OF THE KÖNIGSTUHL OBSERVATORY, HEIDELBERG.

This instrument, which is of relatively very short focal length, is designed for the photography of faint objects and their spectra. With it Dr. Wolf, the director of the Observatory, has done much valuable work on the spectra of known nebulæ, and in the discovery of new ones. Smaller photographic instruments are also used at Heidelberg for the discovery of minor planets. Several hundred of these bodies have been found by Dr. Wolf.

Another observatory in the South of France, that of Marseilles, specialises in the discovery and observation of comets and minor planets, and many bodies of both kinds have been found there by the late M. Coggia, M. Borelly and others, who have also undertaken the laborious but necessary work of computing orbits for the minor planets observed. The determination of time for local distribution, and the making of seismographic records are also part of the regular work of this Observatory, which is not

THE GREAT PULKOWA REFRACTOR.

This fine instrument, whose thirty-inch object-glass was made by Alvan Clark, and the mounting by Repsold, is used principally for the discovery and measurement of close double stars. When erected, in 1883, it was for a short time the largest refractor in the world, but it has since been eclipsed in size by several other instruments.

nearly so well equipped instrumentally as that of Nice.

Germany is well provided with observatories, some of which are of recent construction and splendidly equipped. The only one to which we shall here refer is a comparatively small establishment, which, however, has been doing very interesting and valuable work for many years. This is the Heidelberg Observatory, directed by Dr. Max Wolf, who is one of the most skilful astronomical photographers of our time. The instruments used by Dr. Wolf and his assistants are by no means large, as judged by modern standards, consisting of a twenty-eight-inch reflector of short focus, with spectrograph attached, a sixteen-inch portrait lens, and several cameras of smaller aperture; but an astonishing amount of work has been accomplished with them in several fields of research. The discovery of minor planets by the photographic method illustrated on page 64 was one of the earliest items in Dr. Wolf's programme of work. Starting with lenses of only five and six inches aperture, he soon demonstrated the feasibility of the method. Up to the year 1914 he had discovered over 300 of these tiny planets, most of them being between the eleventh and fourteenth magnitudes, and since then the total has been growing steadily year by year, easily eclipsing that attained by any other worker in this field. In the course of this work Dr. Wolf realised, simultaneously with Barnard in America, the efficiency of the portrait-lens in the delineation of faint and extended nebulæ. Turning to the study of these objects with increased exposures he met with immediate success, and not only discovered several new ones himself (including the "North America" nebula and the external nebulosities of the Pleiades), but also demonstrated the existence of many of the dark patches or "caves" that are now believed to represent obscuring matter. When examining his plates Dr. Wolf was struck with the great number of minute "globular" or "nuclear" nebulæ shown on them (*see* Chapter XIV). Most of these had been hitherto unknown, and Wolf proceeded to make special search for them, recording carefully the position of each. By 1914, when he received the gold medal of the Royal Astronomical Society for his work, he had discovered about 5,000 new nebulæ, and many have been added since then to the number. Various other uses have been found for the great number of plates accumulated in the course of about forty years. By simultaneous comparison in a stereoscope of plates taken at different times many variable stars have been brought to light, and the same method has proved valuable for the detection of large proper motions. In the course of time a large portion of the sky has been covered by the sixteen-inch lens, and prints from the plates, showing stars to about the sixteenth magnitude, are published at intervals by Dr. Palisa at Vienna. They are useful for many purposes, such as the detection of minor planets

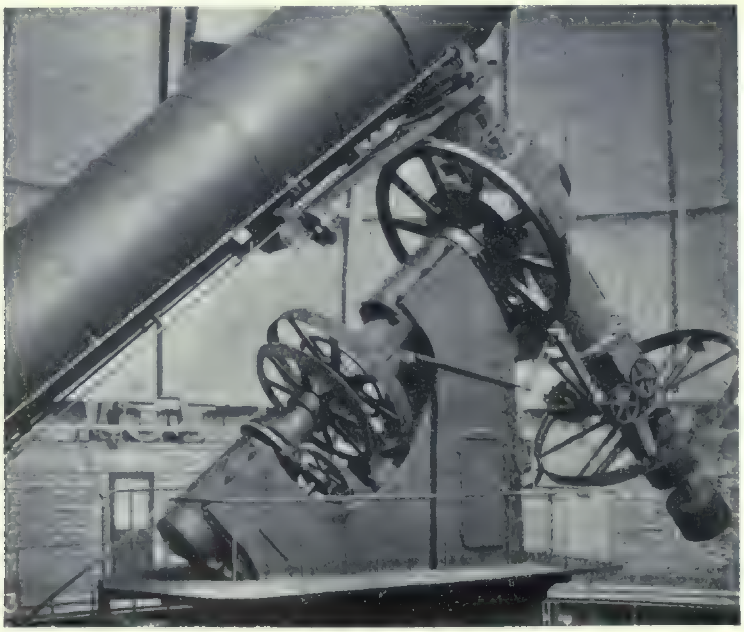
and variables, and the study of the past history of novæ. With the twenty-eight-inch reflector much work has been done on the spectra of nebulæ. For this purpose immensely long exposures are necessary, owing to the faintness of some of the objects. In some cases these exposures have been extended to periods of over seventy hours, spread over several weeks! The work of the Heidelberg Observatory is an outstanding example of the great power of photography as an aid to astronomical research.

Before concluding our survey of some of the observatories of the Old World, mention should be made of a great institution that has done splendid work since the early days of the last Century, though lately much hampered by external events. This is the observatory at Pulkowa, about thirteen miles from the centre of Petrograd. This establishment will always be famous for the immortal labours of the Strüves in the discovery and measurement of double stars. Following on the pioneer work of Wilhelm Strüve with a 9·6-inch refractor (then the largest in the world), most of the earlier work was done with a fifteen-inch equatorial, which, however, was in 1883 supplemented by the addition to the equipment of a thirty-inch refractor. This great instrument, whose object-glass was made by Alvan Clark and the mounting by Repsold, was for a time the largest refracting telescope in the world, and is still one of the largest in Europe. Apart from its connection with double-star Astronomy, Pulkowa is renowned for its meridian work, and for the attention it has given to the problems involved in the determination of star places with the transit-circle. Among other things, the effects

TWENTY-SIX-INCH REFRACTOR OF THE U.S. NAVAL OBSERVATORY, WASHINGTON.
This telescope will always be famous for the discovery by its means of the two satellites of Mars by Asaph Hall in 1877. It is still used very largely for the study of faint satellites and their orbits. The telescope was formerly attached to a mounting of less modern design, which, however, is still in use as a photographic equatorial in another part of the Observatory.

of atmospheric refraction on the apparent altitudes of the heavenly bodies have been investigated with great thoroughness at Pulkowa; and the values there deduced, in relation to temperature, pressure, etc., have been universally adopted by meridian workers.

Turning now to the New World, we have a very wide choice of institutions for description. The development of American Astronomy during the latter half of the Nineteenth Century is one of the most outstanding features of the recent history of the science. This development has been still further extended during the present Century, with the result that the United States now possess quite the best-equipped observatories in the world, and the work that has been done in them has had a profound influence on the progress of Physical Astronomy. It is impossible, in the space here available, to give more than a very brief description of some of these great establishments, and the best idea of the extent and importance of their work is to be obtained by a perusal of most of the chapters of any modern astronomical treatise. A glance through the illustrations alone of the present work will convey some impression of the debt owed by the science to American observatories.



E.N.A.

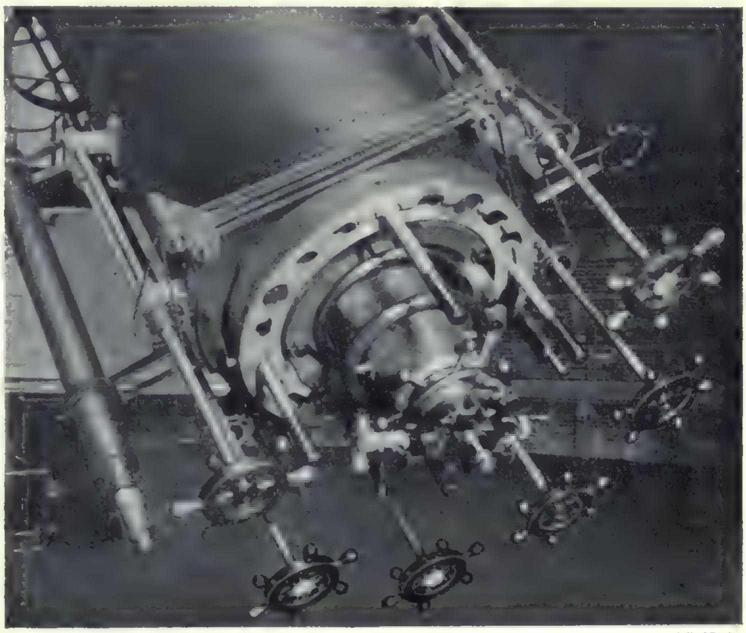
AXES OF THE YERKES TELESCOPE.

In the construction of a large telescope and its mounting considerable demands are made upon the engineer as well as upon the optician. All moving parts, with the bearings in which they turn, have to be fashioned with great accuracy, and the mounting of the whole instrument must be exceedingly rigid and well-balanced without being unduly heavy.

As has been said, it is in the domain of Physical Astronomy that the contributions of the United States have been most noteworthy. There is, however, at least one observatory that is devoted entirely to the Astronomy of position. This is the U.S. Naval Observatory at Washington, which is the Greenwich of America. It is here that data are accumulated for the "American Ephemeris," the publication that corresponds to the British "Nautical Almanac" and the French "Connaissance des Temps." For this, as in similar national observatories, the transit-circle is the most important item in the equipment, and the observations made with it are used in calculating the positions of Sun, Moon, planets and stars. In addition to this more important work the Observatory specialises in the observation of planetary satellites and the computation of their orbits. This work is done with a refractor of twenty-six inches aperture, which is none too large in view of the faintness of some of these small bodies. The instrument was for a time the largest of its kind in the world, and is famous for the discovery of the two satellites of Mars, made with it by Asaph Hall in 1877. Since then it has been provided with a more modern mounting, but the old one is still in use, having been adapted to carry several large photographic telescopes, employed for the photography of minor planets and other objects, for position.

Among its older and more modestly equipped observatories America can boast of a unique institution that has exercised and still exercises a most important influence on the progress of Astronomy. This is the observatory of Harvard College, at Cambridge, Mass. Broadly speaking, its chief work may be described as the study of starlight in nearly all its aspects. We have seen in Chapter XV how the gradual increase in the number of known variable stars led to a demand for the accurate determination

and standardisation of apparent stellar magnitudes. To meet this demand many experiments were made in different parts of the world with instruments of various types, but it was at Harvard that the nearest approach to success was attained, and the magnitudes determined there with Pickering's meridian photometer have been universally accepted as standards for subsequent work. In the observatory's earlier days its photometric work was done entirely by visual means, but later photographic methods were introduced, to supplement rather than to replace the older system of magnitude determination. An immense amount of experimental work of both kinds has been done, full accounts of which are to be found in the Harvard Annals, the medium whereby the researches of the Observatory are made available to astronomers at large. One unique feature of the photometric work at Harvard is of special interest. This is the constant repetition of small-scale photographs of the sky for the detection of variable stars by comparison of their images on the plates. On every fine night a number of similar cameras (each of one-inch aperture and thirteen inches focal length) is exposed to different portions of the heavens, all being simultaneously driven and controlled by electric impulses from a single clock. Many hundreds of variable stars have been discovered by comparison of the plates thus secured, and the photographs, all carefully stored and numbered, form definite records of the state of the sky at the times at which they were taken, and have proved very valuable in tracing the early history of novæ and other objects.



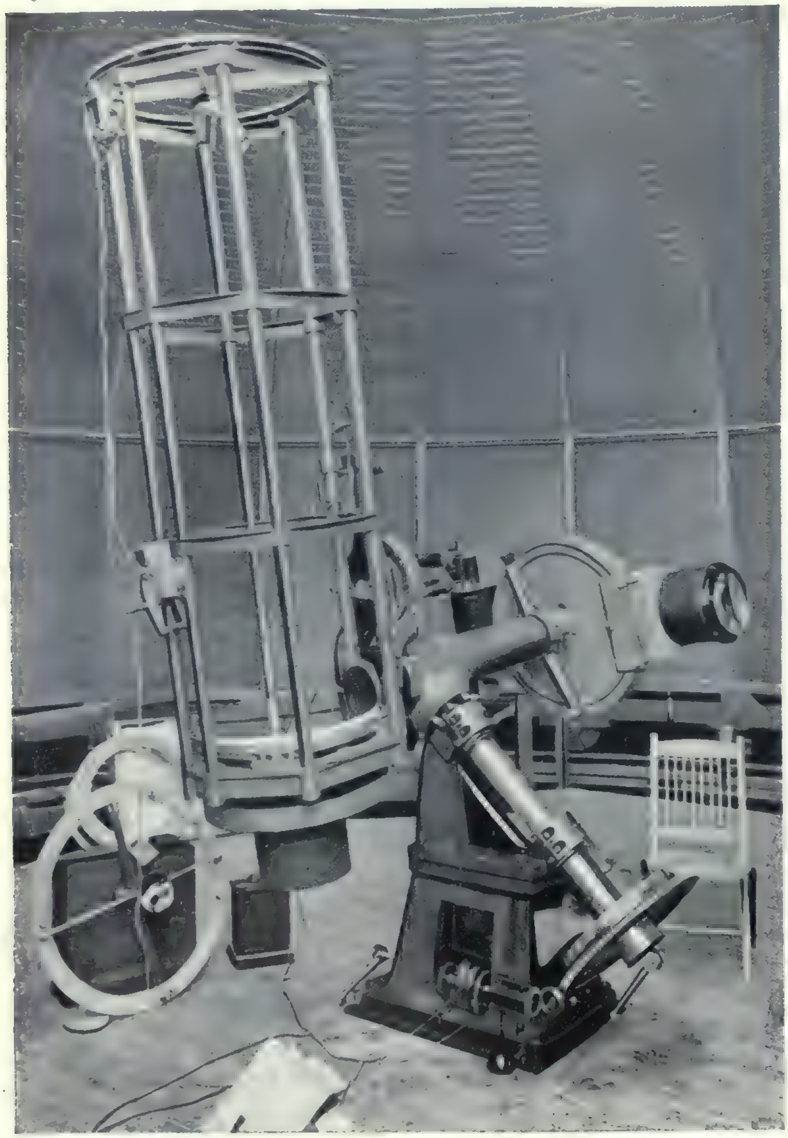
[E.N.A.

EYE-END OF THE YERKES TELESCOPE.

The mechanical arrangements of the "small end" of a large telescope appear at first sight rather complicated. The long rods, fitted with wheel-handles, are the Right Ascension and Declination clamps and slow motions, with their duplicates. The four bare steel projections from the heavy ring at the end of the big tube are for the attachment of spectrographs and similar apparatus. To the left is mounted the small "finder," parallel with the larger telescope.

It is not only our system of photometry that we owe to Harvard College, but also the classification of stellar spectra that is now in universal use. This classification, which is described in detail in Chapter XII, was evolved from the comparative study of a great number of spectra photographed at the Observatory. It has had to be modified from time to time, but the nomenclature adopted is that of the original sequence introduced at Harvard. For the general classification of spectra great dispersion is not necessary; and, if the work is to be rapid and comprehensive, the slit spectrograph, confined in its action to one star at a time, is obviously unsuitable. Hence, most of the work at Harvard is done on a small scale with the objective prism, with which a large number of spectra can be photographed simultaneously on a scale just sufficiently large for purposes of classification. An example of the type of plate produced by this method is to be found on page 68. Thousands of the brighter stars have had their spectra classified and published at Harvard, most of the work having been done by the highly-skilled women members of the staff, among whom may be mentioned the late Mrs. Fleming, the late Miss Leavitt, and Miss Cannon. Harvard provides us with a splendid example of the kind of work that can be done in Astronomy with instruments of small or moderate size. The largest telescopes in the Observatory, though not the ones that do the most work, are the old fifteen-inch refractor always associated with the name

of Bond, a twenty-four-inch photographic reflector, and the five-foot reflector that was made by and formerly belonged to the late Dr. A. A. Common, of Ealing. For many years after its purchase it was not found possible to put this last instrument into regular use, but lately steps have been taken to provide it with work for which its great aperture will make it suitable.



By permission of [*The Yerkes Observatory.*

THE YERKES TWO-FOOT REFLECTOR.

This compact and easily-worked instrument was designed for the photography of nebulæ and faint stars. In this it has done most successful work in the hands of Professor Ritchey, who also figured the mirror. The open-frame tube, now adopted for most large reflectors, has the advantage of eliminating internal air-currents that would otherwise injure the definition of objects photographed. The driving clock, in the base of the mounting, is controlled electrically by the observer, and a double-slide plate-holder is also fitted. (*See* page 525.)

There remain to be considered the three best-equipped observatories in the United States, or indeed in the whole world—the Lick, Yerkes, and Mount Wilson Observatories.

The first of these, founded and endowed by James Lick, is situated at an altitude of 4,200 feet on the summit of Mt. Hamilton, California, being attached to the University of the latter State. It was the first of the great mountain observatories, the success attained there having demonstrated the great advantage of considerable elevation for the site of such establishments. The chief instrument at Lick is the famous thirty-six-inch Clark refractor, which was for many years the largest of its kind in the world. With it the late Professor Barnard discovered the fifth moon of Jupiter and it is one of the few large instruments that have ever been used at all systematically for the study of the surfaces of the planets and their satellites. It is, however, principally used for the visual discovery and measurement of close double stars. A correcting lens, of thirty-three inches aperture, is available for converting the telescope into a photographic instrument if desired, and spectrographic work can also be done with it. The Lick refractor, of which an illustration appears on page 523, also serves as the tomb of its donor, who lies buried in the brickwork portion of the base of the mounting.

Another famous instrument at the Lick Observatory is the Crossley reflector, a photographic

telescope of the same aperture as the big refractor. With it the late Professor Keeler secured the wonderful series of photographs of the nebulæ that has done so much to increase our knowledge of these objects. Some examples of his beautiful work will be found among the illustrations of Chapter XIV, where a picture of the telescope, as originally mounted, is also given. The equipment of the Lick Observatory, of which a general view is to be seen on page 522, also includes a refractor of twelve inches aperture, and a fine transit-circle. On certain nights in the year, according to the provisions of its foundation, the Observatory is open to the general public, and, although a journey of many miles to its isolated site is involved, large numbers of people take advantage of this opportunity of looking through one of the world's largest telescopes.

The munificence of another public-spirited American millionaire, Mr. Charles T. Yerkes, was responsible for the erection of the Yerkes Observatory of the University of Chicago on the shores of

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THE "SNOW" TELESCOPE, MOUNT WILSON.

This unusual-looking structure, referred to locally as the "Ark," was designed to shelter solar instruments from the heating effects of the Sun, which in ordinary telescopes greatly impair the definition by producing air-currents. In the "Snow" telescope there is no tube, the rays of the Sun being directed almost horizontally towards the parabolic mirrors of the instrument by means of the coelostat seen at the near end of the structure.

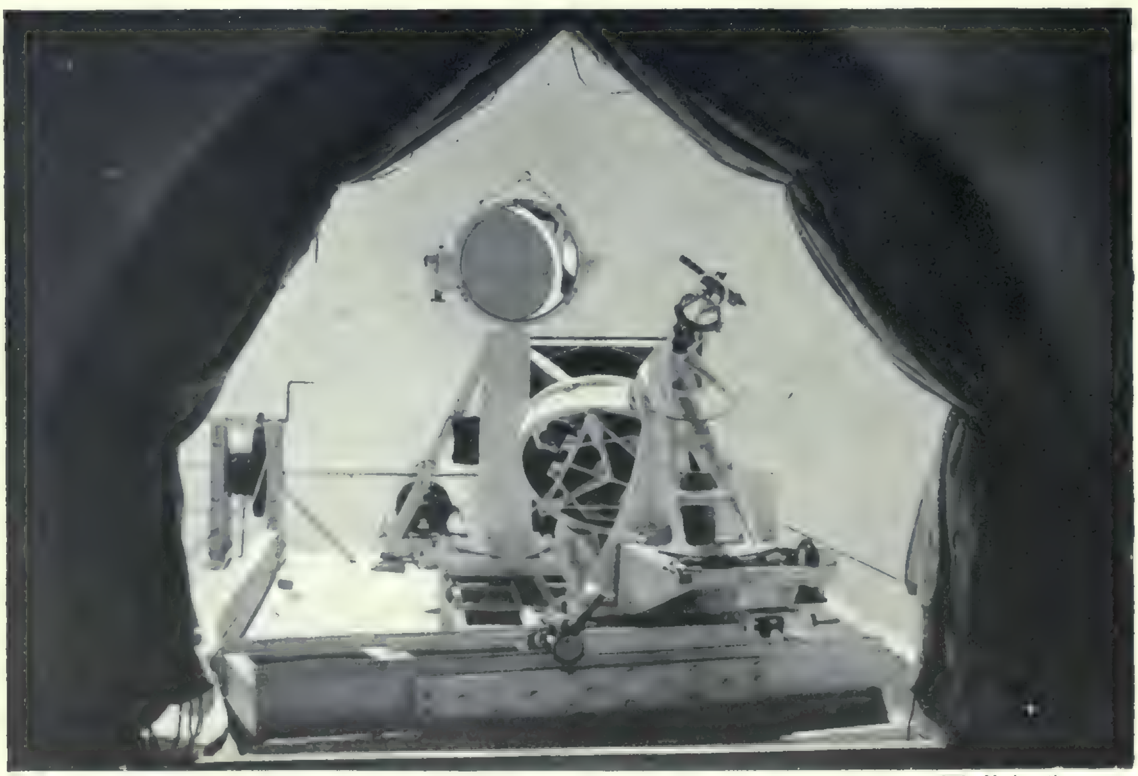
Lake Geneva, about eighty miles from the big city. The main building of the Observatory, which is illustrated on page 70, is constructed of brown Roman brick, and is in the form of a Latin cross. At one end of the longer axis is the great dome, ninety feet in diameter, that covers the forty-inch telescope, which is the largest refractor in the world. This instrument has been and still is put to a variety of uses, its value being so fully realised that it is never allowed to remain idle while the sky is clear. Some of the many purposes for which it is used are parallax work, spectrographic determinations of the radial velocities of stars, visual and photographic photometry, and the measurement of close binaries. Special arrangements are provided for adapting the instrument for each of these purposes, thus making it possible for the one telescope to do the work of several. Some beautiful photographs of the Moon,

planets, and star clusters are among the more spectacular by-products of the work of this instrument, and much valuable visual work of a miscellaneous character was done with it by the late Professor Barnard.

In one of the smaller domes is mounted a photographic reflector of twenty-four inches aperture. It is fitted with an exquisite mirror by Ritchey and has proved most successful in the photography of nebulæ. Away from the main building, in another part of its seventy-acre grounds, is the small structure in which is mounted the ten-inch Bruce photographic telescope, illustrated on page 54. With this little instrument, which is so mounted that it can be pointed in any conceivable direction without fouling the mount, the late Professor Barnard took some of the most beautiful photographs of the Milky Way that have ever been secured. Examples of these will be found on pages 18, 19, and 631. Elsewhere will be found somewhat similar photographs taken by the same observer with a six-inch portrait-lens. It was the great success of these that led to the design and construction of the larger Bruce camera.

The third great modern observatory in the United States is perhaps the most wonderful institution of its kind in the whole world. It is certainly unsurpassed as regards the size and power of the instruments with which it is equipped. Originally designed as a Solar Observatory, and so entitled, it has gradually extended its activities so as to include almost every branch of astrophysical work. As the splendid equipment has grown, the fullest possible use has been made of it, and the Observatory has contributed a very notable portion of the total advance of astronomical knowledge during the past twenty years.

Mount Wilson is situated a few miles from Pasadena, near Los Angeles in California. The summit,



By permission of, *[The Yerkes Observatory.*

COELOSTAT OF THE "SNOW" TELESCOPE.

The coelostat proper, consisting of a plane mirror mounted equatorially and driven by clockwork, is seen in the foreground. By its means the rays of the Sun are directed constantly towards the fixed plane mirror behind, from which they proceed, under cover, down the length of the "Ark," to be received by a parabolic mirror at the end. The image formed by this last mirror is used for various (chiefly spectrographic) purposes of solar research.

on and near which the Observatory is built, is 5,900 feet above sea-level. This position, which secures the maximum freedom from coastal fog and low-lying clouds, makes for the transparency and good definition so essential for the best astronomical work. One of the greatest difficulties in the way of solar research is the unsteady condition of the atmosphere brought about by the heat of the Sun. Not only are currents thus formed in the atmosphere as a whole, but the parts of it near the ground are greatly disturbed by radiation from the latter, or even from parts of the instruments with which observations are being made. By the location of a Solar Observatory on a mountain-top, much of the general turbulence of the atmosphere is left behind at lower levels, but the local causes of disturbance mentioned above are by no means eliminated. The observers at Mt. Wilson soon discovered this and were led to the design and construction of two unusual forms of instrument, both of which have proved very successful in reducing the effects of local atmospheric tremors. In each case the telescope itself is fixed in one position, being " fed " with sunlight by a coelostat in the manner already described earlier in this chapter. In the one instrument the optical axis lies in a nearly horizontal position, the several parts of the apparatus being arranged on a series of concrete pedestals, set in a line. The whole, with the exception of the coelostat and secondary mirror, is covered by an immense canvas-covered structure, with louvred sides. The object of this is to shelter the optical parts of the instrument from the effects of direct and re-radiated sunshine, while allowing of a free circulation of air within the structure. The whole instrument, illustrated on page 801, is known officially as the Snow Telescope, and unofficially (for obvious reasons) as the "Ark." In the second of the novel solar instruments at Mt. Wilson the object-glass, with the coelostat feeding it, is mounted at the top of a tower, the optical axis in this case being vertical. Actually there are two instruments of this kind on the mountain, the more recent of the towers, 150 feet in height, having been built as a result of the success of the earlier one of 60 feet. The steel girders of which the 150-foot tower telescope is constructed are encased in an outer sheath not in contact with them. This is a necessary precaution against rapid changes of temperature and the swaying effects of violent wind. Below the tower is a well in which the temperature is nearly constant, allowing of the successful employment of accessory apparatus that is very sensitive to the alternating effects of heat and cold. Both the Snow and Tower telescopes are used for spectrographic and spectroheliographic work on the Sun under high dispersion. An examination of the spectroheliogram on page 177 will give some idea of the success attained at Mt. Wilson in securing good definition for large-scale solar work.

DOME OF THE HUNDRED-INCH REFLECTOR, MOUNT WILSON.
This is the largest observatory dome in the world. One hundred feet in diameter and weighing a hundred tons, it is nevertheless rotated easily and rapidly by powerful electric motors, allowing of observations in all parts of the sky. It is painted white and provided with a double sheathing to reduce the heating effects of the Sun during the day. The instrument which it covers is illustrated on page 39.

It is impossible here to give details of the immense amount of work accomplished in that part of the Observatory which deals with sidereal Astronomy. The principal instruments used in this connection are the 60-inch and 100-inch reflectors, illustrated respectively on pages 525 and 39. Both

these telescopes are, optically and mechanically, of the highest excellence, as is proved by the beautiful definition of fine detail in the photographs taken with them. Neither is used exclusively for any one kind of work, since experiments have shown that they can be made to fulfil a great variety of purposes almost equally well. Among these may be mentioned the photography of star clusters and nebulæ, the study of the spectra of faint stars, the determination of stellar parallaxes by trigonometric and spectroscopic methods, bolometric observations of stellar spectra, and the photography of the lunar and planetary surfaces. To this list must be added the measurements of stellar diameters made with the twenty-foot interferometer attached to the larger instrument. The effective focal length of each telescope can be varied to suit the particular requirements of different researches, and the same applies to the dispersive power of the spectrographs attached to the instruments. The great value of these large reflectors is fully realised by those who are privileged to use them and care is taken that neither is allowed to rest in idleness while the sky is clear.

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In the brief review which has here been given of the work and equipment of some of the world's observatories no attempt has been made to give anything like an exhaustive account of any one of them. It is perhaps well to repeat at this point that the omission of certain well-known establishments is in no way intended to imply that they are of little importance. The choice of observatories for mention has rather been dictated by a desire to present to the reader the greatest amount of variety both as regards the work done and the type of instruments employed.

Among the most striking features of the work of our large modern observatories will have been noted the almost universal adoption of photographic methods as a substitute for the older processes

By permission of *The Yerkes Observatory.*

SPECTROSCOPIC LABORATORY, MOUNT WILSON.

In this laboratory experiments are made under conditions that can be controlled by the observer, and the information thus gained is of great value in interpreting the results of spectrographic work on Sun and stars, and in suggesting further lines of research. A laboratory is a necessary adjunct to every modern astrophysical observatory, and the one at Mount Wilson is specially well-equipped.

of visual observation. While no one can deny the enormous advantages thereby realised in certain departments of research, it may perhaps be felt that Astronomy must inevitably lose some of its romance for the man to whom a star is nothing but a small black mass of silver grains, or a series of parallel lines, on a glass plate. But there are still certain branches of work in which the direct use of the eye is acknowledged to give the best results, and some of our greatest professional workers, such as the late Professor E. E. Barnard, have always kept this in mind. Moreover, in whatever directions the professional of the future may be forced to develop his methods, we may be confident that the great company of amateurs will never allow visual observation to become a lost art.

From] [" *Knowledge*."

150-FOOT TOWER TELESCOPE, MOUNT WILSON.

In this case the telescope is fixed in a vertical position, the light of the Sun being reflected down it by a coelostat and secondary mirror mounted at the top of the tower. The latter is made of steel, with a separate outer sheath for each girder. This is a precaution against the effects of wind and rapid changes of temperature. Below the tower is a well, whose nearly constant temperature allows of the successful employment of very delicate instruments, as accessories to the main telescope.

CHAPTER XXII.

THE CALENDAR.

BY REV. T. E. R. PHILLIPS, M.A., F.R.A.S.

IN Chapter XIX, Mr. Bartrum has dealt with the important subject of time, and has described various devices and mechanical appliances for its measurement. It requires little reflection to see how all-important a thing it is in any stage of civil or community life, that a knowledge of the hour of the day or night should be ascertainable with some approach to accuracy, and although certain experiments, as described by Mr. Dingle in Chapter XVIII, have led to the establishment of the relativity of time as well as space standards, yet without some system of units (which have sensibly the same value for all the inhabitants of this planet), the refinements of organised social life would be impossible.

As already remarked, a natural division of time is that provided by the Earth's axial rotation which produces the alternation of day and night, but for many purposes longer intervals of time are needed. Some of these are supplied for us in nature, others are arbitrary or conventional. Among the former may be mentioned the month, which is related to the movements of the Moon; and the year, which is dependent on the Earth's revolution round the Sun.

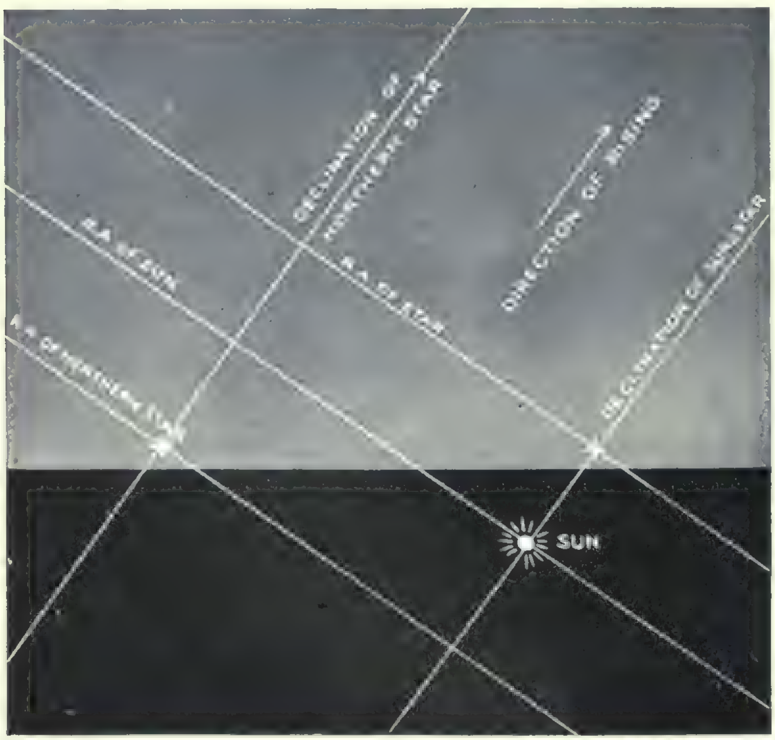
Among the divisions of time which are more or less conventional, not being dependent on definite recurrences in nature, we may place the week, which has varied in length among different nations between five and ten days; the Greek Olympiads, which were successive intervals of four years, and the Roman Indictions, or intervals of fifteen years instituted by Constantine in the year A.D. 312 in connection with the collection of taxes and the keeping of accounts, and still used for the purpose of dating by the Papal Court. But for the common affairs of life, as well as for the provision of points of reference in historical records, the fundamental division of time is the year. Associated with this is

the sequence of the seasons and the succession of agricultural operations; hence, also, the arrangement of civil and economic life. On the other hand, from the earliest times the month has also been an interval of the highest importance, since so many religious observances have been associated with the Moon's phases; and the incommensurability of these two important intervals of time is the main cause of the confusion that has arisen in chronology as well as in the observance of important annual events.

The word calendar (or kalendar) is derived from the Latin *kalendæ*, the name assigned to the first day of the Roman month. It is now commonly applied to any scheme of time-division in which the year is adopted as the fundamental unit. But it must be remarked that the term "year" in this connection is used rather loosely, being in some calendars applied to a succession of months rather than the journey of the Earth round the Sun. The Mohammedan year, *e.g.*, consists of twelve months, or 354 days only, so that the fasts and festivals in the course of about thirty-three years, go completely through the seasons.

Before going further, it is necessary for us to consider what exactly we mean by the terms "year" and "month" in calendar problems. Although the year is generally understood to be the time required for the Earth to travel round the Sun, or, which comes to the same thing, for the Sun to make its circuit of the sky in the ecliptic, it may as a matter of fact be defined in three distinct ways, each of which has a time value slightly different from the others. As has been already explained in Chapter II, the Earth's orbit is an ellipse and in consequence of the disturbing effect of the other planets the direction of its major axis or line of apsides is slowly changing. It is moving forward in the direction of the Earth's motion. If then we reckon the year by the Earth's motion from perihelion through aphelion to perihelion again, we shall get a slightly greater value for the length of the year than if we reckon it by the return of the Sun to the same point in the sky as indicated by the stars. This latter interval is known as the sidereal year, and the former (that referred to the perihelion point) as the anomalistic year. But neither of these years is the one we need as the basis of our calendar, since the alternations of the seasons depend neither on the Earth's return to perihelion nor on the position of the Sun relative to the stars, but on its position relative to the equator.

Now it will be remembered that the Sun's path or the ecliptic intercepts the celestial equator at two opposite points known as the vernal and autumnal equinoctial points; and the interval between two successive returns of the Sun to the same equinoctial point is

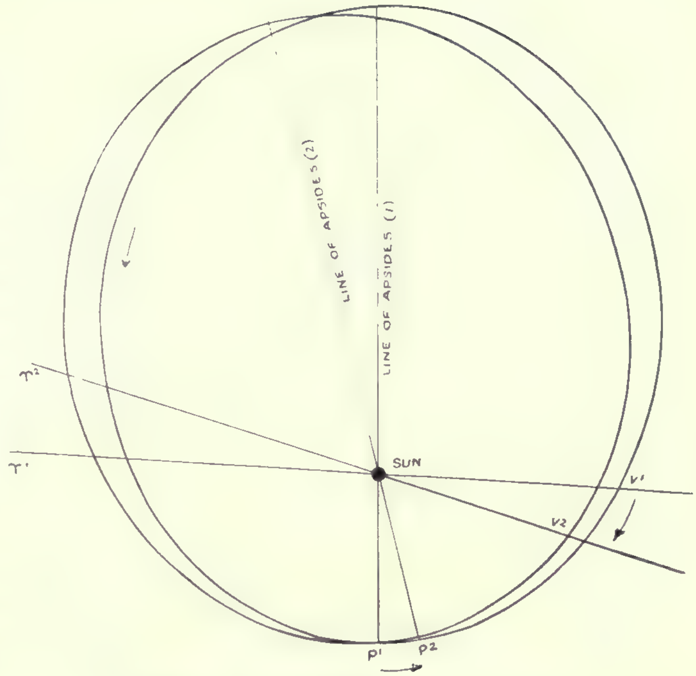


Drawing by, *W. H. Steavenson.*

HELIACAL RISING OF A STAR.

The length of the year was probably determined in early times by the observation of stars visible near the horizon about sunrise or sunset. In the diagram a star of the same declination as the Sun has just risen before it. Note that in the northern hemisphere a star north of the Sun may rise before it, even though its Right Ascension be greater. The same thing is true of a star south of the Sun in the southern hemisphere.

the interval in which the seasons recur. This, then, is the year we want for calendar purposes, and it is known as the tropical year. But as explained in Chapter V, p. 236, the Earth's axis, in consequence of the disturbing action of the Sun and Moon—especially the Moon—on the protuberant ring of matter round the Earth's equatorial regions performs a conical movement about the poles of the ecliptic in 25,800 years. This involves a backward motion of the equinoctial points round the ecliptic in the same interval of time. It follows, then, that whereas the anomalistic year (reckoned by the Earth's return to perihelion) is longer than the sidereal year, the tropical year is shorter than the sidereal year. The three kinds of year are illustrated in the figure on this page.



THREE MEASUREMENTS OF THE YEAR.

The diagram (not drawn to scale) represents the Earth's orbit at two epochs—say 12 months apart. P^1, P^2, and V^1, V^2, are its positions at perihelion and the vernal equinox at these two epochs. Note that the line of apsides is advancing, while that of the equinoxes is retrograding (precession). The interval between returns of the Earth to the same direction as seen from the Sun (say from P^1 to the direction of P^1 again) is the *sidereal* year; that between returns to perihelion (P^1 to P^2) is the *anomalistic* year; and that between returns to the equinox (V^1 to V^2) is the *tropical* year.

Probably the earliest determinations of the length of the year were based on observations of the heliacal rising or setting of certain prominent stars, that is, by counting the number of days between successive first appearances of the same star in the east just before sunrise, or successive last appearances in the west just after sunset. Such observations gave very approximately the length of the sidereal year, but measures of the shadow cast at noon by a gnomon—indicating at what intervals the lengths are equal, revealed the duration of the tropical year and hence led to the discovery of precession. By such means as these the tropical year was found in very early times to comprise about 365¼ days. We now know its length to be 365 days 5 hours 48 minutes 46·15 seconds, which is about twenty minutes less than that of the sidereal year and twenty-five minutes less than that of the anomalistic year.

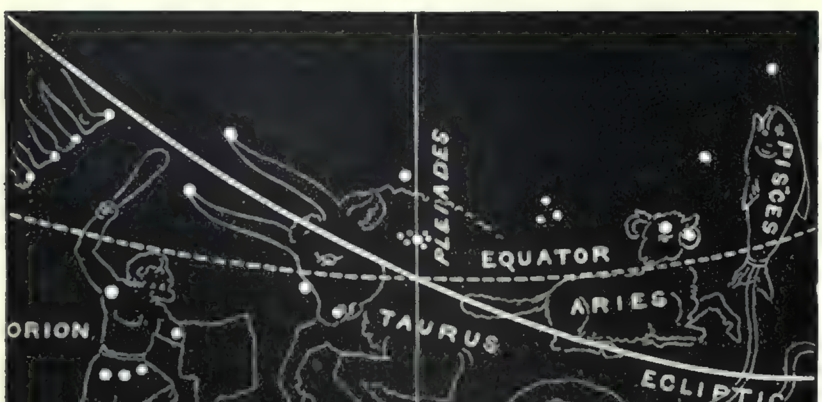
We must also consider what we mean by the month in relation to the calendar, and here again we have a word which is used with a variety of meanings; to mention just three of these, there is the month as measured by the return of the Moon to very nearly the same direction in the heavens (the sidereal month), the month as measured by the Moon's return to one of its nodes (the nodical month), and the month as indicated by the lunar phases (synodic month), and these all have different values.

It will be clear that since the Moon's nodes are regressing (like the equinoctial points above mentioned) the nodical month is shorter than the sidereal month, whereas, owing to the forward motion of the Earth round the Sun, the synodic month, or the interval from any new Moon to new Moon again, will be longer than the sidereal month. (*See* figure on page 816.)

Now, the month which has always been associated with religious observances is the synodic month. It will be remembered, for example, that amongst the Jews, the month was considered to begin on the evening on which the thin crescent of the new Moon was first seen in the western sky and the fact was announced by the blowing of trumpets. The synodic month, then, (commonly called a lunation) is the month which formerly entered into the consideration of calendar problems. Its length is just over

twenty-nine and a half days or more exactly 29 days 12 hours 44 minutes 2·87 seconds, the day here being the mean solar day, or the mean interval throughout the year between successive returns of the Sun to the meridian as described on p. 693. This is nearly four minutes longer than the day as measured by returns of a star to the meridian, owing to the motion of the Earth in its orbit round the Sun. We now see the nature of the task which the calendar maker had before him. He had to fit together as best he could the tropical year, the synodic month, and the day, or rather to devise means for surmounting the difficulties that arise from the incommensurability of these important intervals of time.

Generally speaking, the calendar adopted has been one of three main types. It has been purely solar, purely lunar, or luni-solar. In the first of these the year is taken as fundamental, and the lengths of the months are arbitrary, being merely conventional, and without relation to the lunar phases. The typical example of such a calendar is that inaugurated by Julius Cæsar, a calendar which, with a very slight modification to be described presently, is substantially the calendar we use to-day. On the other hand, in a purely lunar calendar the length of the month is taken as fundamental, and the year consists, say, of twelve lunations or 354 days without any reference whatever to the seasons. The Mohammedan year, mentioned above, is the outstanding example of this type of calendar. In a luni-solar calendar the year usually consists of twelve lunations (the months being alternately twenty-nine and thirty days) with an intercalary or embolismic month added from time to time as may be necessary to keep the year in approximate agreement with the seasons. The Jewish calendar was a striking example of such endeavours to fit together both the month and the year. It will be remembered that the Paschal celebrations were always associated with the season of spring, and at the Passover, which fell at the full Moon of Nisan, the first green ears of barley had to be presented. If then in any year at the new Moon of the month, which was expected to be Nisan, it was found that such ears of barley would not be ready in time for the Passover, the beginning of Nisan was postponed for another lunation ; and in this way the Jewish calendar was maintained in approximate agreement with the tropical year. The Greek calendar was also a luni-solar one, a cycle of eight years being adopted, during which the normal lunar year of 354 days was supplemented three times by an intercalary month of thirty days. There seems to be some uncertainty about the nature of the early Roman calendar. According to some authorities the year consisted of ten months only, and it has been stated that the two months January and February were afterwards added by Numa. Others dispute these statements. It is, however, quite certain that in early times the Romans made use of an intercalary month, which they called Mercedonius, consisting of twenty-three days. This has also been attributed to Numa. Later, under Julius Cæsar, the Roman calendar became, as mentioned above, definitely solar, being associated with the tropical year which, as we have seen, is roughly $365\frac{1}{4}$ days in length. Cæsar introduced his reform with the assistance of the Alexandrian astronomer, Sosigenes, and in order to allow for the odd quarter of a day it was ordained that in



THE VERNAL EQUINOX.
The diagram indicates the position of the "Vernal Equinox" (the point of intersection of the equator and ecliptic), more than 4,000 years ago. It was then situated in Taurus.

EFFECT OF PRECESSION.
This illustration shows how the Vernal Equinox has "precessed." From Taurus (*see* previous diagram) it has moved back to the western part of Pisces, which is outside the region here mapped to the right.

every fourth year the sixth day before the kalends of March—that is February 24—should be counted twice. For this reason those years were called *bissextile* years. They are now generally known as leap years. It also appears that Cæsar decided to begin the year on January 1, instead of in March, and at the same time had the name of the month Quintilis—or the fifth month reckoning from March—changed to Julius (or July) after himself. Similarly his successor Augustus changed the name of the following month Sextilis (the sixth month) to Augustus or August, and it is said that he also took a day from February and added it to August in order that the latter might not be less in length than the month associated with his predecessor Julius. In this way the length of February, which had been primarily twenty-nine days, was reduced in common years to twenty-eight days.

The Julian calendar was not, of course, adopted without some chronological dislocation, and the year before the commencement of the new system—that is, 46 B.C., according to our common reckoning —had to be prolonged to 445 days in order that certain festivals might fall about the times originally assigned to them in the tropical year. This year is generally known as the "year of confusion." Some confusion also *followed* the inauguration of the new calendar in consequence of a misunderstanding of the rule relating to the bissextile years, but after the errors thus introduced were corrected—that is, about half a century after its inauguration—the Julian calendar continued in use in European countries without any change or interruption down to the latter part of the sixteenth century. In Russia and the East it survived without change until quite recently.

No doubt the abandonment of all attempt to combine the year and the succession of lunations in one scheme and the decision to make the calendar a purely solar one was akin to a stroke of genius. Nevertheless, the Julian calendar suffered from one small defect which was cumulative and gradually assumed proportions which were found inconvenient. That calendar was based, as we have seen, on the assumption that the tropical year is 365¼ days or 365 days 6 hours exactly, whereas the true length is 365 days 5 hours 48 minutes 46·15 seconds. The assumed tropical year was accordingly some eleven minutes fourteen seconds too long, with the result that the equinoxes gradually fell earlier and earlier in the year according to the calendar date. Now from the beginning it had been the habit of the Christian Church to celebrate Easter about the time of the full Moon falling on or next following the vernal equinox, and at the time of the General Council of Nicæa, that is, in A.D. 325, the equinox was held to occur on March 21 (it actually fell that year on the evening of March 20). It does not seem that the Council actually prescribed the method of determining Easter but merely ordained that Christians everywhere should keep the festival on the same day. Nevertheless, in accordance with tradition this was subsequently interpreted as meaning that Easter should be observed on the Sunday after the first full Moon falling on or after the 21st of March. Since, however, from the cause above mentioned the equinoxes gradually fell earlier and earlier disputes arose as to the correct date of Easter. The matter was carefully considered by sundry General Councils, especially by the Council of

From "Astronomy for All", *[By permission of Messrs. Cassell & Co., Ltd.*

SUNRISE AT STONEHENGE AT THE SUMMER SOLSTICE.

The point of Sunrise varies throughout the year. The most distant stone shown in the illustration was so placed as to indicate the position at the Summer Solstice, or the longest day. The Sun is shown rising behind the stone's tip.

Trent, and in 1582 Pope Gregory XIII, who was assisted by the Jesuit astronomer Schüssel, generally known as Clavius, issued a Bull decreeing (1) that to restore the date of the vernal equinox, which then fell on March 11, to March 21, the day following October 4 in that year should be called October 15, and (2) that, in order to prevent a recurrence of the dislocation, only those century years which are divisible by 400 should be considered as leap years. By this rule 1700, 1800, and 1900 were not leap years, but 2000 will be a leap year.

The reformed calendar—known as the Gregorian calendar—is not quite correct, although very nearly so. By the rule of the centurial years three years in every four centuries which would be leap years according to the Julian calendar become common years, or, on the average, one in 133 years, whereas the true correction should be one in 128 years. The outstanding error, however, is small, and will not amount to a single day till the expiration of between 3000 and 4000 years.

The new calendar came into operation at once in those countries which acknowledged allegiance to the Pope, but the Eastern Church and most Protestant States refused to adopt it until much later. The change was not made in Great Britain till 1752 and even then not without considerable opposition and disturbance. Parliament decreed that the day following September 2, 1752, should be called September 14 instead of September 3, and, notwithstanding the care that was taken to guard against any possibility of injustice in the collection of rents and other payments, riots broke out in various places and the cry was raised "give us back our eleven days." It may be remarked that the difference between the two calendar systems had now become eleven instead of ten days as in 1582, since under the new rule 1700 was not a leap year.

Another change that was made at the time when the Gregorian calendar was adopted in England relates to the beginning of the year. Prior to 1752 the official date of its commencement had been March 25, but this was now put back to January 1, the date which had been chosen for the beginning of the year by Julius Cæsar and also by Pope Gregory XIII at the inauguration of the new system in 1582. It is, however, worth noting that January 1 had been regarded as the first day of the year in Scotland since 1600, and even in England the intercalation of the additional day every fourth year had been made in the February *preceding* not in that *following* the March which was officially the first month of the year. To avoid confusion in the dates of events occurring in January, February or March about the period of change from the old to the new calendar it is usual to give the years according to both styles. For instance, February 20, 1753, according to the old style, would be written February 20, 1753/1754. But although for ordinary civil purposes January 1 is New Year's day, everyone who pays rates and taxes knows that the financial year of the British Exchequer begins on April 6. This is really a survival from the time when the year began on March 25. At the adoption of the new style in

1752, in order that there might be no change in the length of the current financial year, the calendar date of its commencement was put forward eleven days to April 5. But the old style was for some reason still retained; and the year 1800 not being a leap year on the Gregorian system, April 6 took the place of April 5 in the Nineteenth Century. In 1900, however, which was also not a leap year, the date of the commencement of the financial year remained unchanged, so that like the ordinary civil year the year of the Exchequer is now determined by the Gregorian rule.

It may be well at this point to refer shortly to our adopted system of numbering the years from the supposed date of the birth of Christ. This system did not obtain in the early days of the Christian Church, but is due to Dionysius Exiguus (Denis le Petit), said to have been an Abbot of Rome in the sixth century. A cycle of 532 years in which Easter recurs on the same dates in the Julian calendar had already been discovered by Victorius Aquitanus, and Dionysius readjusted the beginning of the first of these cycles to make it coincide with what he believed to be the year in which our Lord was born. It scarcely falls within the scope of this chapter to discuss the very interesting chronological point here raised, but it is believed that, while accepting the tradition that that year was the twenty-eighth of the reign of Augustus, Dionysius made the mistake of reckoning from the assumption of the name Augustus by Octavius instead of from a date four years earlier (723 in the era of Rome) when the battle of Actium was fought in which he had gained his famous victory over Antony and Cleopatra, and from which the reign of Augustus is commonly counted. The date now generally accepted as that of Christ's birth is accordingly 4 B.C., but for a full and interesting discussion of the subject the reader is referred to Chapter XIII of Mr. Alexander Philip's book, "The Calendar: Its History, Structure and Improvement."

We may now consider some of the chief defects in the calendar which have led in recent years to a growing demand for reform.

To begin with, the date of the commencement of the year is not a suitable one, strictly speaking

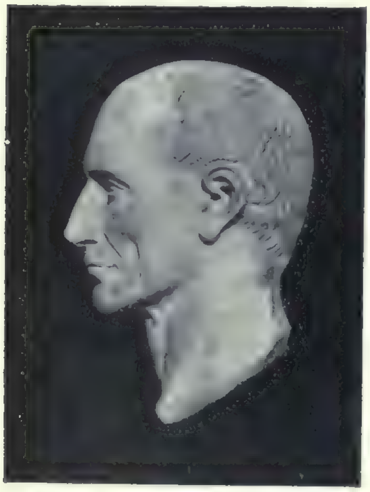
From "Astronomy of the Bible" *By E. W. Maunder.*

"BLOW UP THE TRUMPET IN THE NEW MOON."

Amongst the Jews the month was held to begin on the evening when the thin crescent of the New Moon was first seen, and the fact that it had begun was announced by the blowing of trumpets. The times of their religious observances depended on the phases of the Moon, and their year consisted of twelve lunations with an extra month added, when needed, to keep their feasts in agreement with the seasons.

from the scientific point of view, since January 1 marks no outstanding epoch in the relative positions of the Sun and Earth. It has been suggested that the most natural date for the beginning of the year would be that which we now call December 22, since it is the date when the Sun having reached its greatest southern declination is about to turn and travel north again. It may be questioned, however, whether any such readjustment at this stage of the world's history would not result in more dislocation and confusion than advantage, since the gain would be merely a technical one, except perhaps for such things as the discussion of meteorological statistics. And even here the change would probably be of advantage to observers in the northern hemisphere only. Considering the world as a whole, perhaps one of the equinoctial dates would be preferable as the commencement of the year if any change at all were considered desirable.

But a far more serious defect in our existing calendar than the arbitrary date of its commencement is the inequality in the divisions of the year into months, quarters, and half-years. The inconvenience is felt in commercial and business affairs such as the arrangements of accounts and the calculation of salaries, interest, pensions, rent, and so forth. In Great Britain the quarters as reckoned from Lady Day, Midsummer Day, Michaelmas Day, and Christmas Day contain in common years ninety, eighty-seven, ninety-seven and ninety-one days respectively, and even if we divide the year according to the calendar months the intervals are ninety, ninety-one, ninety-two and ninety-two days. The first "half" of the year thus contains only 181 days, and the second "half" 184 days. Now, as has been pointed out with much force by Mr. Alexander Philip, who has devoted an immense deal of time and research to calendar problems, a simple and effective reform could be secured with a minimum of disturbance by simply taking a day from August and adding it to February. If this were done, the quarters would consist of ninety-one, ninety-one, ninety-one and ninety-two days respectively, each quarter being easily divisible into thirteen weeks with just one extra day in the last quarter, about which more will be said later. There can be no doubt that this slight change in the month, which is really only the correction of a stupid blunder originating in the vanity of Augustus, even if no other corrections were made, would be of great benefit in business and trade transactions as well as in other departments of civil life. Another suggestion which has been made, and which would produce a similar result with the additional advantage of greater symmetry in the monthly divisions, is that each quarter should consist of three months of thirty-one, thirty and thirty days successively with the extra day at the end of the last quarter. This would, of course, mean a slightly greater disturbance of our present system. Yet another proposal is to divide the year into thirteen months, each of which would consist of twenty-eight days or four weeks exactly (neglecting for the moment the odd day), but the dislocation involved in this readjustment is so considerable that it would probably receive but scant support.



JULIUS CÆSAR, THE DICTATOR.
One of the greatest men of antiquity. He inaugurated in 45 B.C. with the help of Sosigenes, the Calendar System which is the basis of that which we use to-day.

It will be noticed that in any attempt to arrange the year in equal divisions the odd day presents a difficulty which is insuperable. It also prevents the calendar being a perpetual one—a type which not a few people engaged in business transactions think desirable. For were the year to consist of 364 instead of 365 days, the same dates would always fall on the same days of the week year after year, an arrangement with certain obvious advantages. Accordingly it has been proposed to remove the obstacle in the way of a completely orderly calendar by excluding December 31 from the general scheme—making it, in short, a blank day or *dies non*, so that it would be neither a Sunday, nor a Monday, nor a Tuesday, nor any other named day of the week, but an extra and uncounted day which might be a general holiday. In leap years there would, of course, be two such days, one probably being arranged to follow the last day of June and the other that of December. Each half year would thus have an

extra day attached to it without upsetting the orderly progression of calendar events. But it seems likely that this proposal would meet with strong opposition, particularly in certain religious quarters. Our week is of extremely ancient origin. It has come down to us through thousands of years without any interruption. Even at the time of the Gregorian reform there was no breach of continuity in its sequence, so that the exclusion of one or two days from the calendar would involve the upsetting of a tradition which has about it the glory of a great antiquity together with a definite religious significance. It may be argued that the principle underlying the week with one day in seven assigned to special religious obligations would not be seriously disturbed, but ancient traditions are not to be lightly thrown aside, and many will doubtless feel that a much stronger case for the necessity or desirability of this proposed change must be made out than is apparent at present before their opposition to it can be withdrawn.

The problems just referred to have been considered at various conferences, one of the most important of which was held at Rome in May, 1922, during the meeting of the International Astronomical Union. On that occasion the Commission specially appointed for the consideration of calendar reform approved the following proposals: (1) The adoption of a perpetual calendar, keeping fifty-two weeks plus one or two blank days. (2) January 1 to take the place of the day at present occupied by December 22. (3) The 364 days to be divided into four periods of ninety-one days each, *i.e.*, two months of thirty days and one of thirty-one, without excluding an auxiliary division into periods of fourteen and twenty-eight days.

[*From a portrait at Stonyhurst.*

POPE GREGORY XIII.

In 1582 Gregory XIII corrected the error of the Julian Calendar by slightly modifying Cæsar's rule of the leap years. He also readjusted the Calendar date of the spring equinox to March 21, the assumed date in A.D. 325.

We have deferred to the latter part of this chapter the discussion of a proposed reform which is commonly regarded as the most pressing, though it would probably be one of the most difficult on which to secure a general agreement; namely, the stabilisation of Easter. This, of course, does not involve any question fundamental to the calendar such as the accuracy of the length of the tropical year, but it relates to the observance of a festival which occupies a key position in the Ecclesiastical Calendar, and also affects certain commercial, industrial, legal, and educational interests, which by ancient custom have been linked up with it. As mentioned above, it has been the rule of the Church from the beginning to celebrate Easter about the time of the Jewish Passover, when the Crucifixion and the Resurrection took place, that is about the time of the full Moon of the Jewish month Nisan. It is true that the actual coincidence of Easter with the Passover was to be avoided, as is shown by the provision that if the full Moon falling on or next after March 21 happens upon a Sunday, Easter Day is the Sunday after. It is also the case that differences in the time of the Passover and the Easter celebrations arise from differences in the rules whereby the Paschal Moon is determined, the Moon of the Jews being based on the rules laid down by Hillel in A.D. 358 and that of the Christian Easter on certain cycles (to be described), with occasional readjustments. Nevertheless, the traditional association of Easter with the Paschal Celebration has been adhered to from very early times down to our own day; and that notwithstanding our use of a calendar which in all

From a portrait at Stonyhurst.

THE JESUIT ASTRONOMER, CLAVIUS.

Clavius was the chief of Pope Gregory's advisers. To correct the error of the Julian Calendar it was decided that only those century years should be leap years which are divisible by 400 without remainder.

other respects is a purely solar one and quite independent of the lunations.

But the existing system of keeping Easter obviously means a considerable oscillation in the date of the festival. The full Moons which determine it may fall between the limits of March 21 and April 18, so that by the rule adopted the earliest and latest dates for Easter are March 22 and April 25—a range of no less than thirty-five days!

It is beyond our scope to discuss here in detail the rules in use by western Christendom for finding Easter; but a few words by way of general explanation may be of interest. At the outset we may remark that the moon on which the occurrence of the festival depends is not the actual moon of the heavens, which is obviously "new" on a day the date of which differs according to the longitude of the observer, but a conventional moon which can be adopted all over the world, and which we may call the *Calendar Moon*.

This moon depends on a cycle of nineteen years, at the end of which the Sun and Moon return to very nearly the same positions relatively to the Earth. During these nineteen years there will be 235 lunations, so that the new Moons and full Moons during this interval of time will repeat themselves about the same dates in successive cycles. How near the agreement is will be seen from the following figures:—

		d.	*h.*	*m.*	*s.*
19 Julian years	=	6939	18	0	0
235 lunations	=	6939	16	31	14

This cycle of nineteen years is generally known as the Metonic Cycle, after the Athenian astronomer Meton, who discovered it in about the year 433 B.C., though it seems to have been known previously in China and elsewhere.

But there is another point to be remembered in connection with Easter. It must fall on a Sunday, and in consequence of the odd day at the end of the year the Sundays in successive common years occur on dates earlier by one day, and of course they fall two days earlier after February in the leap years. The result is that the Sundays will not return to the same dates till the expiration of twenty-eight Julian years, so that the complete cycle for Easter, according to the Julian system, is $19 \times 28 = 532$ years. This is the cycle discovered by Victorius or Victorinus Aquitanus and adopted, apparently, by Pope Hilarius in A.D. 463. It was this cycle, too, which Dionysius Exiguus readjusted so as to make its commencement coincide with the supposed date of Christ's birth as stated above.

Now, it will be obvious that under the reformed calendar of Gregory certain corrections to this system of finding Easter are necessary. Tables in which they are embodied are given at the beginning of the English Book of Common Prayer. They were compiled by Bradley, who was Astronomer Royal at the time of the adoption of the Gregorian calendar in England, and as explanations of their use accompany them, little need be said about them here.

The Golden Number is the number of the year in the so-called Metonic Cycle as readjusted by Dionysius. The name has its origin in the fact that the numbers of the years in Meton's cycle with the dates of the new Moons are said to have been inscribed in letters of gold on the walls of the temple of Minerva at Athens. The Dominical, or Sunday letter, is the letter assigned to the days

on which the Sundays in the year fall; the first seven letters of the alphabet being assigned to the days of the successive weeks, beginning with A for January 1, B for January 2, etc., and A again for January 8, and so forth. It will be obvious that owing to the odd day over and above fifty-two weeks at the end of the year, the Sunday letter will retrograde one place each year, except in leap years, when the additional day in February will cause it to retrograde a second place. Leap years will accordingly have two Sunday letters.

Clavius, the chief adviser of Gregory XIII, made use of the Epact for the calculation of Easter Day. The word Epact (derived from the Greek *epaktos*, which means *added*) refers to the eleven days which must be added to twelve lunations (354 days) to complete the tropical Year (365 days).

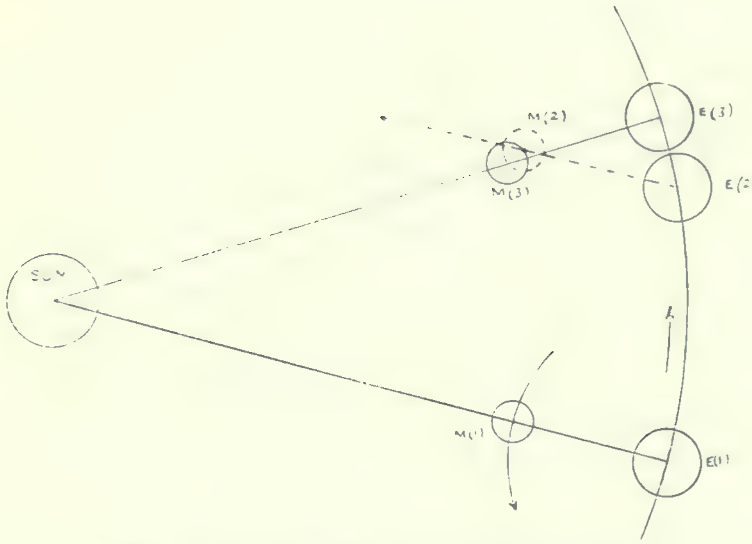
Now supposing a new Moon to fall on January 1 in a given year, on January 1 in the following and the remaining eighteen years of the lunar cycle, the age of the Moon would be eleven, twenty-two, three (deducting thirty as being a complete lunation), fourteen . . . . twenty-nine days respectively, and at the beginning of the next cycle ten, twenty-one, two, etc., the numbers retrograding by one in each successive cycle. Owing, however, to small outstanding errors which are cumulative, there is need of readjustments from time to time to keep the Epacts right with the Calendar. It will be clear that from the Epact for any year which is the age of the Calendar Moon on January 1, the date of the Full Moon occurring on or next after March 21 can be readily found, and this determines Easter by the rule above given.

Now the oscillation in the date of Easter through a range of thirty-five days obviously involves certain inconveniences both in ecclesiastical and civil affairs, and there is in many quarters a demand for fixing the occurrence of the festival within much narrower limits. To do this would, of course, involve a break with ancient tradition and an agreement on the point by the various

[E.N.A.

THE TEMPLE OF MINERVA.

Ruins of the Temple of Minerva, on the walls of which it is said the number of the year and the dates of the full Moons in the cycle of Meton (nineteen years) were inscribed in characters of gold.



THE SIDEREAL MONTH AND THE LUNATION.

Three positions of the Earth in its orbit are shown. At E(1) the Moon is "new." At E(2) the Moon, having meanwhile travelled round the Earth, is seen at M(2) in its original position relatively to the stars and a *sidereal* month has been completed. But the Earth must travel as far as E(3) to give the Moon time to get round to the direction of the Sun (at M(3)), when it will be again "new." Accordingly, the month as measured by the Moon's phases (*lunation*) is longer than the sidereal month (29·5 days to 27·3 days).

ecclesiastical authorities, which would be very desirable, or, indeed, necessary, if a change is to be made, might prove extremely difficult to secure. This question, amongst other Calendar problems, was discussed at a Conference convened by the League of Nations at Geneva, at the end of August and beginning of September, 1923, at which the Roman, Eastern Orthodox, and Anglican Churches were represented by the Rev. Father Gianfranceschi, S.J., President of the Academy "Dei nuovi Lincei," Professor D. Eginitis, Director of the Observatory of Athens, and the writer, respectively. It was agreed that there is no insuperable objection to the fixing of Easter on dogmatic grounds, but it was felt that such a departure from the Church's ancient rule would be likely to meet with considerable opposition. However, this and other Calendar proposals were left open for further discussion in the near future, after they have been considered by the various ecclesiastical and civil authorities concerned.

But supposing an agreement to fix Easter should eventually be arrived at; what Sunday, it may be asked, is most likely to be chosen? It seems obvious that the most suitable day would be the Sunday which falls closest to the actual dates of the events commemorated, supposing such can be ascertained. Now we know that Our Lord was crucified on a Friday at the time of the Passover, during the Governorship of Pontius Pilate at Jerusalem, and there are two dates which seem to satisfy the required conditions, namely, April 7 in the year A.D. 30, and April 3 in the year A.D. 33. The former of these is generally believed to be the more probable, but in any case they are close together. If, then, Easter were fixed for the second Sunday in April it would almost always fall within a very few days of the commemorated event, and it would be much more accurately an anniversary than is the case under the existing rule.

We conclude this chapter with a reference to what is called the Julian date. From what has been already written it will be clear that the dates of past events are extremely liable to confusion and uncertainty owing to differences in the calendrial systems adopted. Accordingly, for the purpose of avoiding all possibility of misunderstanding in the statement of dates, J. Scaliger proposed in 1582 a cycle known as the Julian Period, consisting of 7980 ($28 \times 19 \times 15$) Julian years, its adopted starting point being January 1, 4713 B.C. and the year A.D. 1 being J.E. (Julian Epoch) 4714. In recording certain observations of astronomical phenomena, however, such as observations of variable stars, it is usual to give simply the number of the day without mention of the year. January 1, 1924, *e.g.*, is denoted J.D. (Julian day) 2,423,786, which is the number of days elapsed at Mean Noon.

It may be remarked that although, unfortunately as many people think, in 1925 and after the common astronomical day, like the civil day, will begin at midnight, the Julian day will continue to begin at noon.

CHAPTER XXIII.

ASTRONOMY IN NAVIGATION.

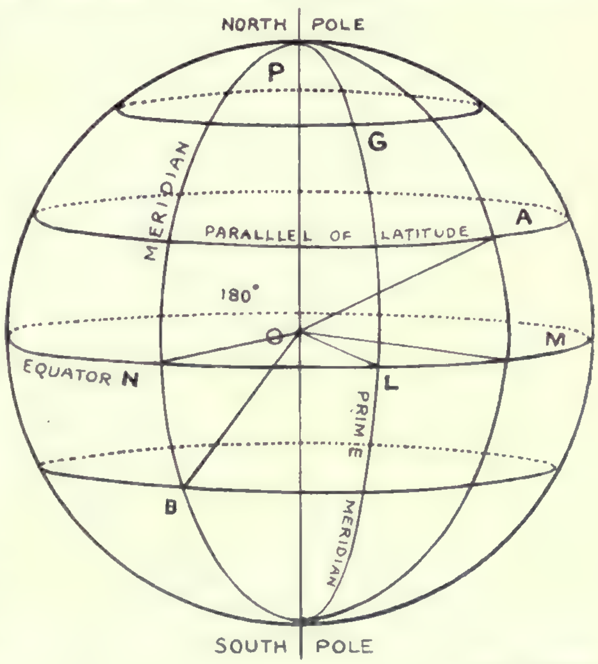
BY INSTRUCTOR CAPT. M. A. AINSLIE, R.N., F.R.A.S., F.R.M.S.

OF all the useful applications of Astronomy to modern life, none surpasses in importance its application to Navigation. It is of course true that position-finding by wireless telegraphy, which has already proved of great utility and will, in the near future, in all probability be greatly developed, bids fair to displace astronomical observation to a considerable extent, and may take its place altogether ; but for the present, as a general means of determining the position of a ship when out of sight of land, astronomical observation is indispensable.

Before dealing with the principles on which the application of Astronomy to Navigation is based, let us consider for a few moments what is the problem to be solved. When we speak of the " position " of a ship, what do we mean ?

In describing the position of a point on a sphere, such as the Earth very nearly is, we must define it by two measurements or co-ordinates : and those in universal use are Latitude and Longitude. The reader is probably well acquainted with the meaning of these terms, but it may not be out of place to remind him that Latitude is the distance of a place from the equator—or, if preferred, the angle between the radius of the earth through the place and the plane of the equator—measured north and south in degrees and minutes. This definition is sufficiently correct for almost all purposes in Navigation, but it assumes that the Earth is accurately spherical. A more accurate definition of latitude is that it is " the inclination of the vertical at the place to the plane of the equator." A vertical, or " plumb " line, owing to the Earth being slightly compressed at the poles, does not lie along a radius—that is, does not point quite to the centre—except on the equator or at the poles. The difference, however, so far as concerns the finding of a ship's position, is practically unimportant.

Latitude, it will be seen, is defined by a natural circle—the equator ; this, being equidistant from the poles, is fixed by the Earth's axis, which is not an arbitrary line. Longitude, however, has to be reckoned from some arbitrary zero or starting point. Great circles—*i.e.*, circles whose plane passes through the Earth's centre—can be drawn through the poles and at right angles to the equator ; that half of such a circle, measured from pole to pole, which passes through a given place is called the " Meridian " of the place. The longitude of the place is the angle between the meridian of the place and some fixed meridian arbitrarily selected, measured about the poles : or it may be regarded as the arc of the equator between the points where it is cut by the fixed meridian and that of the place. At one time each nation had its own zero meridian, from which longitudes were measured ; but for many years now, by common consent of almost all nations, that through Greenwich has been the zero, and is called the " Prime Meridian." Longitude is



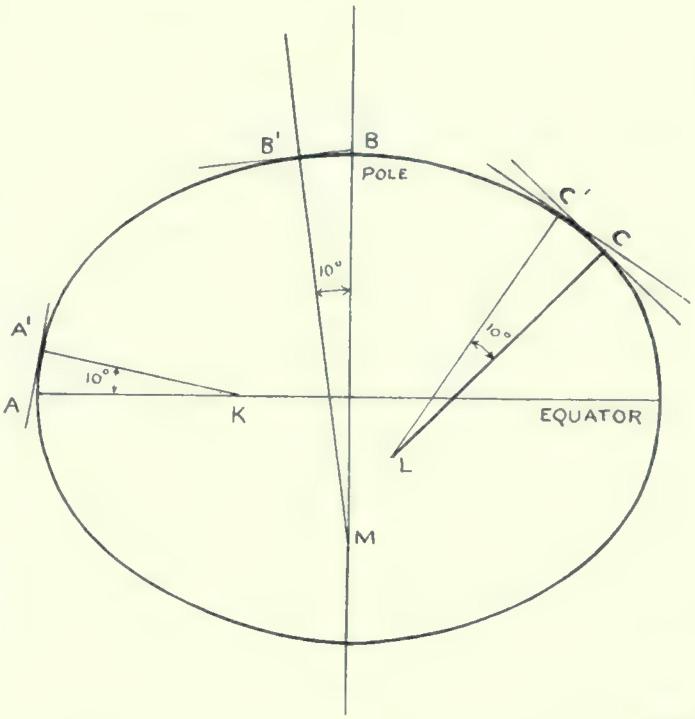
[*M. A. Ainslie.*

LATITUDE AND LONGITUDE.

This diagram may serve to remind the reader of the meaning of these terms. The latitude of the point A may be taken either as the length of AM or as the angle AOM ; and the longitude of A is either the length of LM, or the angle MOL, or the angle LPM at the pole P. A is in north latitude and east longitude, B in south latitude and west longitude. O is, of course, the centre of the Earth, and G represents Greenwich.

measured east and west from the prime meridian, up to 180° only.

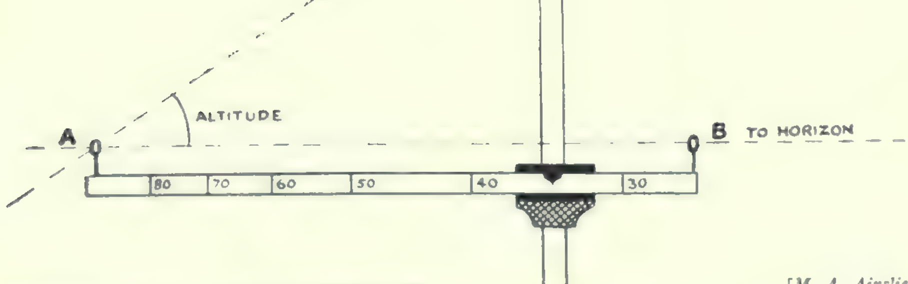
Distances, in navigation, are measured by a standard unit; the length corresponding to a single minute of latitude on the Earth's surface is called a "nautical mile," or, when we deal with navigation, simply a "mile." It is, in fact, the distance that must be travelled on the Earth's surface, along a meridian, in order that the direction of the vertical, or plumb, line may alter by one minute of angle. The Earth being flattened at the poles to the extent of about one part in 293 (the Earth's equatorial diameter is 7926·8 land or "statute" miles, and its equatorial diameter 7899·8), the curvature of the surface at the poles is less than at the equator. Thus one would have to proceed rather farther along a meridian at the pole than at the equator before the plumb line would alter its direction by one minute of angle: the length of the nautical mile is, strictly speaking, greater at the poles than on the equator. Its length in various latitudes is given by the following table :—



[*M. A. Ainslie.*

VARIATION IN THE LENGTH OF THE NAUTICAL MILE.

In this figure the polar flattening of the Earth is very greatly exaggerated; if it were drawn in true proportions the flattening would be quite invisible. The arcs AA′, BB′, CC′, each represent 10° difference of latitude or 600 nautical miles, and it is evident that the length of these arcs increases with increasing latitude, being least on the equator and greatest at the poles. KA, KA′, LC, LC′, etc., are all at right angles to the Earth's surface, *i.e.*, in a vertical direction at A, A′, etc.



[*M. A. Ainslie.*

THE CROSS-STAFF.

This illustrates the principle of one of the old instruments used to obtain the altitude of a celestial object at sea. The sights A, B are directed to the horizon, and the vertical arm is slid along the horizontal arm until the object observed comes in line with C, the eye being at A. The altitude is then read on the scale on the horizontal arm.

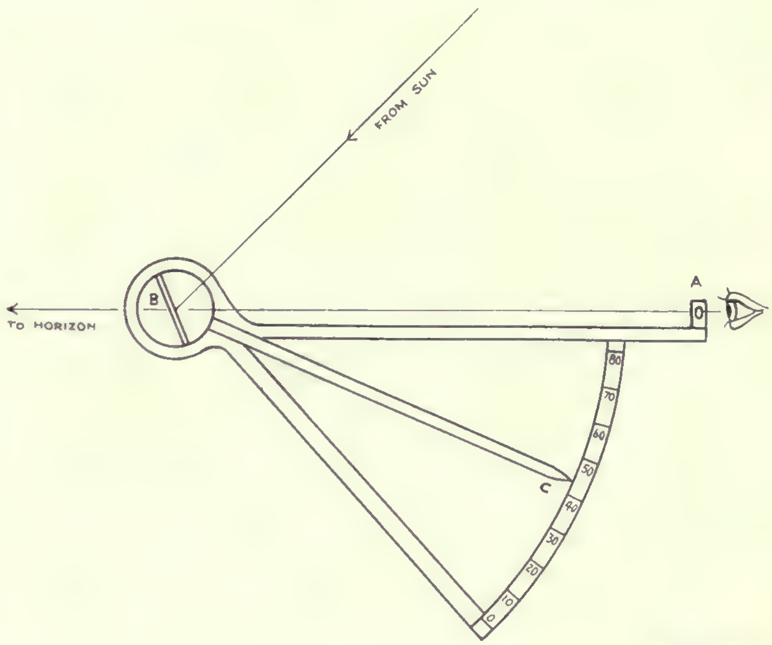
Latitude, N. or S.	*Length of Nautical Mile in feet.*
0° (equator)	6045·7
15°	6049·8
30°	6061·2
45°	6076·7
60°	6092·3
75°	6103·7
90° (poles)	6107·9

For practical purposes, in British charts and publications, the length of the nautical mile is taken to be 6,080 feet, which is almost exactly its true value in latitude 48° N. or S. This is called

the "Admiralty Nautical Mile." (It may as well be pointed out here that the nautical mile is not the same thing as the "knot," although this error, in popular literature, is very commonly committed. The "knot" is a *velocity,* not a *distance:* it is the *speed* of one nautical mile *per hour.* If such an expression as "thirteen knots per hour" means anything, it is that the ship's speed is increasing at the rate of thirteen knots every hour; it would be what mathematicians call an "acceleration," not a "velocity." The proper expression is simply "thirteen knots".)

In passing it may be remarked that those engaged in the daily practice of navigation, or—as the writer was for many years—in daily instruction in the subject, may be thankful that the Earth's "polar compression" is as small as it is. Navigators on the surface of Saturn, for example—if there are any, which is highly doubtful—would have to deal with a polar compression of one part in about nine and a half. The nautical mile, therefore, at Saturn's equator, would be 46,179 feet, while at his poles it would be no less than 64,455 feet—a difference of something like forty per cent.!

In any astronomical observation which has for its object the determination of the position of a celestial body at any moment, we have to use some points or circles of reference; in a fixed observatory on land these are usually the meridian and the celestial pole (or equator), and fixed instruments —transit circles, altazimuths, etc.—are provided for the purpose. But from the nature of things the navigator is deprived of these standards—he is on a shifting platform, and his instruments are anything but fixed; and in fact the only observation he can make with anything like sufficient accuracy is that of the distance of a celestial object from his horizon—called its "altitude"—which is usually defined as "the arc of a vertical circle between the horizon and the body." From this, by subtracting from 90°, is obtained the "zenith distance," which is the quantity usually employed in the actual computation necessary to find the position of the ship.



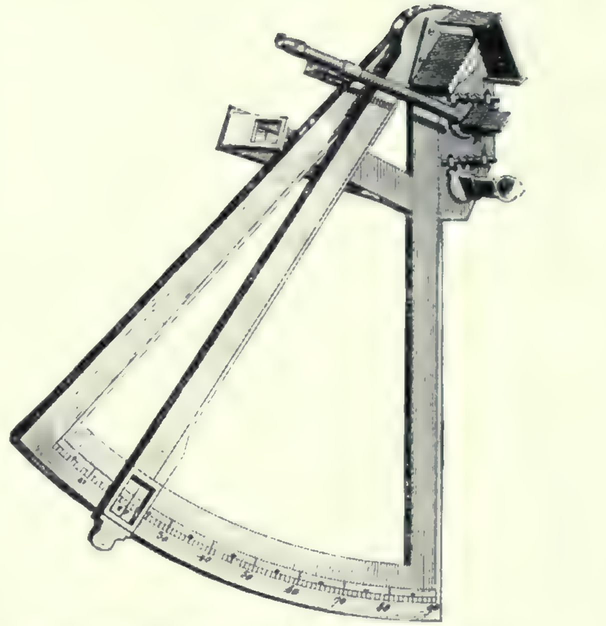
[M. A. Ainslie.

THE BACK-STAFF.

This is an improvement on the Cross-staff, since it is possible to see the horizon and the object observed at the same time, and in the same direction. The observer stands with his back to the Sun (or other object) and gets the horizon in line with the centre of the mirror. He then turns the mirror about B so as to see the Sun by reflection, and reads the altitude on the arc at C.

It will readily be understood that the instruments employed by the navigator for making his fundamental observation of the altitude of a celestial object are likely to be very different from those employed by the astronomer in his fixed observatory on shore; and ever since observations of Sun, Moon, and Stars were first taken at sea, much ingenuity has been devoted to their design. At first the instrument employed seems to have taken the form of a large pair of compasses, one leg of which was directed to the horizon and one to the object observed, the eye being of course at the joint; but such an instrument would be very rough indeed. The first improvement was probably the introduction of sights, similar to those of a gun, which would undoubtedly increase the accuracy of the observation. Another form of instrument used was the "cross-staff"; this consisted of two wooden bars at right

angles, one of which was directed to the horizon, while the other, which could be slid to and fro along the horizontal arm, was adjusted so that its upper extremity came into line with the object. Another form of this instrument had the two bars relatively fixed, and the vertical one had a sliding "foresight" which was brought into line with the object, the altitude being read off on a scale in the vertical bar. The writer has been informed that even at the present time a primitive instrument of this kind is in use on the West Coast of Africa. From the very earliest times it seems to have been noticed that the altitude of the pole star changed as one sailed North or South. The pole star is rather more than a degree from the pole, and since the latitude of a place is equal to the altitude of the celestial pole, the altitude of the pole star would serve as a somewhat rough, but for primitive purposes useful, indication of the latitude. Even if the early navigators were ignorant of the meaning of the term "latitude," they at any rate probably knew that at any given port the altitude of the pole star was more or less constant, and that it could be recorded by a notch cut on the vertical arm of the cross-staff. When at sea, then, all that they



From "The Royal Observatory," by E. W. Maunder.] [Religious Tract Society.

HADLEY'S QUADRANT.

Hadley's Quadrant was the precursor of the modern sextant, and is the same in principle. The instrument illustrated is somewhat more complicated than the usual form, but the principle—that of two images in the same field of view, their relative positions being unaffected by any motion of the instrument—is the same as in the simpler form, and forms the great advantage of the instrument over its predecessors.

By courtesy of] [Messrs. Heath & Co.

THE MODERN SEXTANT.

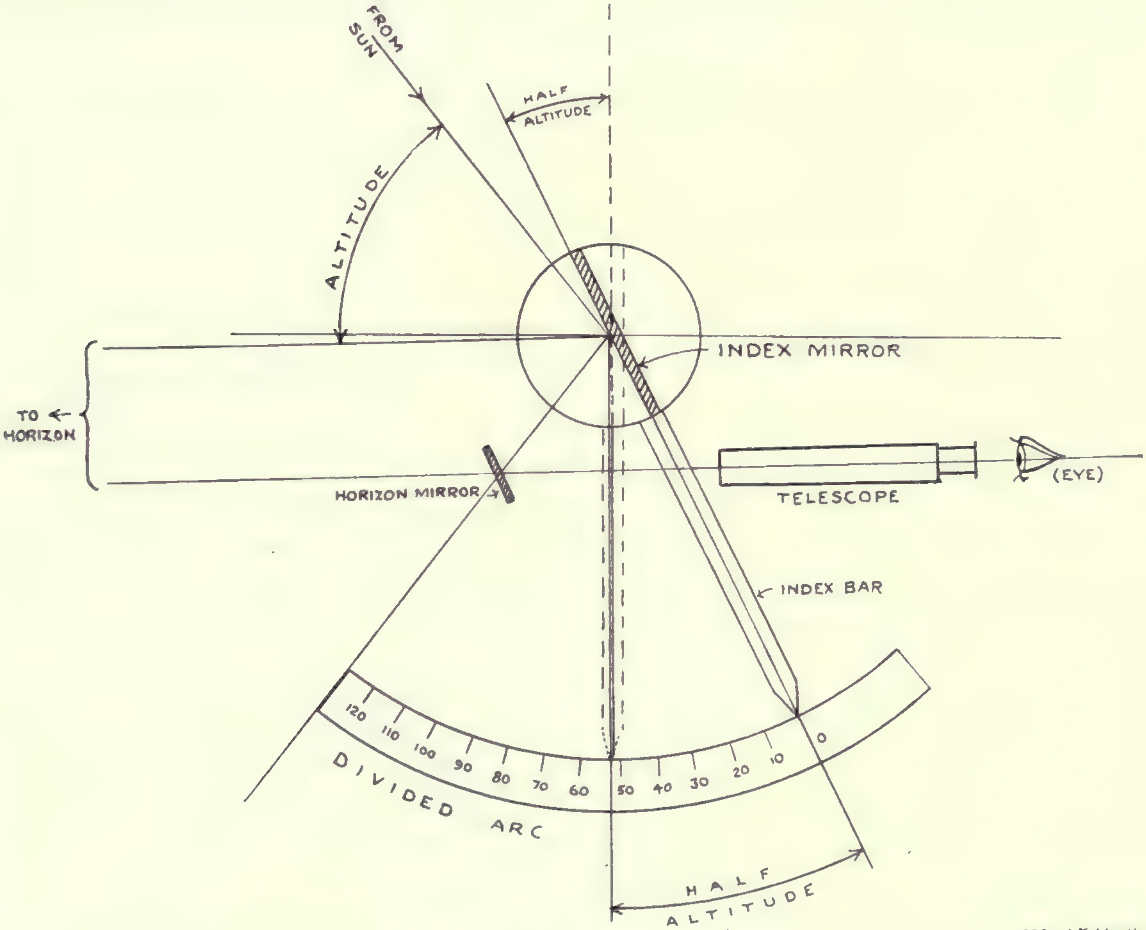
The sextant illustrated is a good example of the best modern practice in design and manufacture; it should be compared with the primitive quadrant shown in the last figure, which, however, is identical in principle. Here the sextant is shown fitted with an inverting telescope, a shade in front of the horizon mirror to reduce the glare from the horizon, and another shade between the mirrors to reduce the light of the Sun.

had to do to make their port was to steer a northerly or southerly course until the pole star came into the notch, when they could steer east or west until they arrived at the coast, when they would at any rate be somewhere near their port.

A further improvement was the "backstaff." In this instrument a mirror pivoted about a horizontal axis so that its inclination could be read from a divided circle, took the place of the vertical arm of the cross-staff, and was fixed at one end of the horizontal arm. The observer stood with his back to the Sun, and directed the arm to the horizon; the mirror was then turned so as to reflect the Sun's light to his eye, and the altitude read off from the divided circle. This method of taking the Sun's altitude was a distinct advance on the preceding, since with the cross-staff it was by no means easy to keep the horizontal arm accurately on the horizon and at the same time to align the sight on the object observed.

With the back-staff, however, both horizon and object were seen in the same direction, and their coincidence could be more easily observed.

The back-staff, however, had one very great disadvantage; unless the instrument was held absolutely steady, the image of the object, and the horizon, were in constant relative motion, and in fact observations were extremely difficult. Some instrument was required in which the relative position of object and horizon, as seen, would remain constant in spite of the motion of the ship and the inevitable unsteadiness of the hand of the observer; and this was provided by Hadley's " Quadrant," invented in or about 1731, which in its modern form of " sextant " is still in universal use by all navigators throughout



[M. A. Ainslie.

THE PRINCIPLE OF THE SEXTANT.

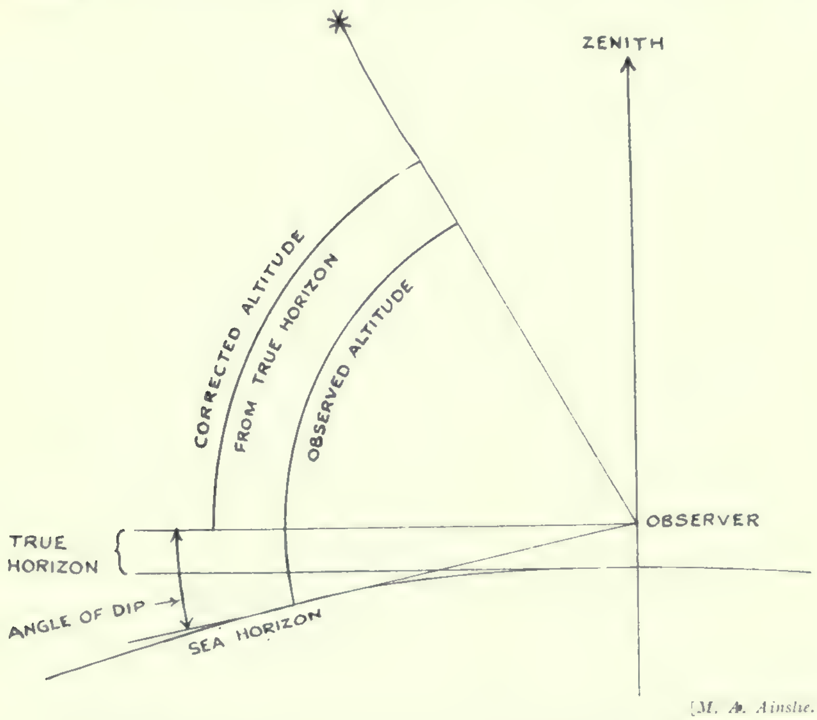
When the mirrors are parallel, the horizon is seen direct through the unsilvered half of the horizon mirror, and (after two reflections from the two mirrors) in the silvered part of the horizon mirror. The index mirror is then swung back towards the observer until the Sun is visible in the horizon mirror, and the altitude read on the divided arc.

the world; the only modification in it being that a telescope is usually employed to view the object and horizon, and that instead of measuring angles up to ninety degrees (whence the name " Quadrant ") it is now capable of measuring angles up to 130 or 140 degrees, so that it is not confined to the measurement of altitudes of celestial objects, but may be used for many other purposes in navigation. Since the actual length of the divided arc of the instrument is rather over sixty degrees, or a sixth of a circle, the instrument is nowadays called a " Sextant."

The above brief account of the early astronomical instruments used in navigation does not pretend to include all, or nearly all, the devices which have from time to time been suggested, but it may be of

interest as tracing roughly the course of evolution of the sextant; and the principle of this beautiful instrument deserves some consideration.

The principle of the Sextant, put briefly, is that the deviation of a ray of light after reflection at two plane mirrors is double of the angle between the mirrors. This will be understood from consideration of the details of the instrument itself. The sextant consists essentially of a frame shaped like a fan, or sector of a circle, on which are mounted two plane mirrors, both at right angles to the plane of the frame. One of these mirrors (called the " horizon glass ") is fixed at about the middle point of one radius of the sector, and the other (called the " index-glass ") is pivoted at the apex of the sector, and from it proceeds a long " index-bar " which lies across the frame, and ends in a pointer travelling along the arc of the sector, which is divided to show the position of the pointer or index. For greater accuracy of reading the pointer usually takes the form of a vernier. The zero of the graduations on the arc is (or should be) adjusted so that the pointer shall read zero when the planes of the two mirrors are parallel. Opposite to the horizon glass, and on the other radius of the sector, is a " sight," which in the old instruments was usually a small aperture to which the eye could be applied, but which in modern sextants is usually a small astronomical telescope of power about six or eight diameters. This telescope is placed so as to point through the centre of the horizon glass, and there is usually an adjustment by which it can be brought, without altering its direction, towards or away from the frame. In order that the horizon may be visible through the telescope, only half of the horizon glass is silvered, the other half—that farthest from the frame—being left clear; the dividing line between silvered and unsilvered portions is parallel to the frame of the instrument. To reduce the light of the Sun to a comfortable intensity, or to avoid the intense glare from the horizon which is common when the Sun's altitude is low, shade glasses of various intensity are provided in front of index and horizon glasses, which are pivoted so as to be swung into line when desired; these, as well as the mirrors, have to be very carefully worked and as accurately plane as possible.

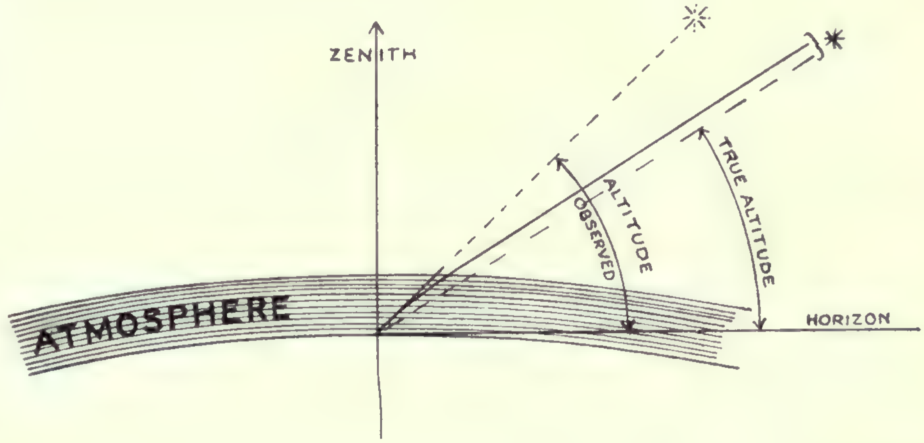


CORRECTION OF ALTITUDE FOR DIP OF THE SEA HORIZON.

The Earth being globular, an observer raised above its surface sees the sea horizon slightly depressed below the true horizon, so that the altitude he observes with his sextant is rather too large. A correction depending on his height above the sea has to be subtracted from the reading of the sextant.

Suppose now that we wish to observe the altitude of the Sun. The sextant is held with its frame vertical and the index-glass uppermost, and the telescope is directed to the horizon at the point vertically under the Sun. If now the mirrors are placed parallel, so that the index or pointer reads zero, an image of the horizon will be seen in the telescope, formed by the rays which have passed directly through the unsilvered part of the horizon glass; an image will also be seen of the horizon, formed by

rays which have been reflected successively from the index and horizon glasses ; since these have been placed parallel, the two reflections cause no deviation of the rays, so that the direct and reflected images as seen in the telescope will coincide. If now we wish to bring the Sun into the field of view, we can do so by swinging the index-glass backwards until it is at the proper angle to reflect the Sun's rays to the horizon glass and thence to the telescope. To do this the pointer has to be moved along the arc, and away from the observer ; and a little consideration of the well-known law of reflection will indicate that the angle through which the pointer and index-glass must be moved is exactly *half* the Sun's altitude. If then the graduations on the arc are made *half degrees*, but marked and read *as degrees*, it is evident that the Sun's altitude can be directly read off from the arc without further trouble. As all the computations of solar observation have to be based on the altitude (or zenith distance) of the centre of the Sun's disc, and this is not an observable point, it is usual to observe one limb (generally the lower) of the Sun and to apply a correction for the apparent semi-diameter as obtained from the Nautical Almanac. (This applies also to the Moon.) The limb is adjusted, by means of a slow screw motion applied to the pointer or index-bar, so as just to touch the horizon as seen in the telescope ; for most observations the time of the observation is also noted by a watch which is compared with the chronometer. The accuracy of reading by means of the vernier usually fitted is ten seconds of arc (or, in the latest pattern of "Admiralty" sextant, 0·2 minute), but as a rule a single observation cannot be depended on within about one minute, except perhaps under very favourable conditions.



[*M. A. Ainslie.*

CORRECTION OF OBSERVED ALTITUDE FOR ATMOSPHERIC REFRACTION.
On passing through the atmosphere the light from an object is bent downwards towards the Earth, so that an observer sees the object at a greater altitude than is really the case. A correction has to be subtracted from the observed altitude, depending on the altitude ; at the horizon it is about half a degree, about 1′ at 45°, and zero in the zenith.

The position of a place on the Earth's surface being commonly defined by its latitude and longitude, the most obvious thing would appear to be to make an observation of the Sun or other celestial object furnish us with one or other of these two coordinates ; and this was, until comparatively recently, the common practice. Ever since astronomical observation was applied to the determination of the position of a ship at sea, it was found a fairly simple matter to determine the latitude ; we have already seen that this is given (rather roughly) by the altitude of the pole star, and the observation of the altitude of a celestial object on the meridian is a ready and convenient method of determining latitude with considerable accuracy. The zenith distance of a celestial object on the meridian (commonly known as "m.z.d.," or meridian zenith distance) is always either the sum or the difference of the latitude of the place and the declination of the object ; the difference, if latitude and declination are both north or both south, and the sum, if they are of "opposite names." The zenith distance is of course obtained by subtracting the altitude from ninety degrees, and the declination is given for any day by the Nautical Almanac, and corrected for the time of the observation ; a simple addition or subtraction sum then gives the latitude. In the event of clouds preventing observation of the altitude of the Sun or other celestial object on the meridian, an observation near the meridian may be made, by means of the

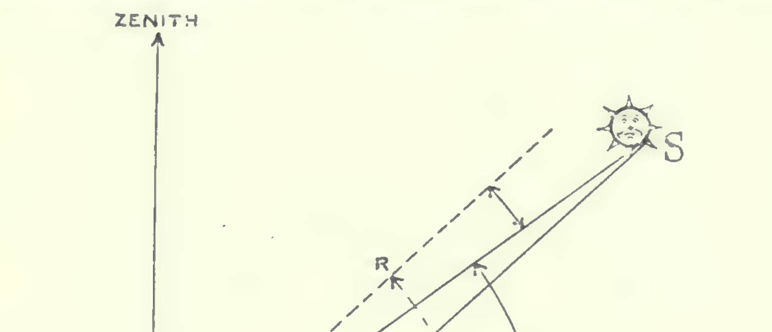
application of small corrections for which convenient tables have been constructed, to give the latitude with almost the accuracy obtainable from a meridian observation.

But it was quite otherwise with the other co-ordinate—the longitude. From the earliest times the determination of longitude presented difficulties which proved insurmountable until the motions of the Moon were sufficiently well understood to enable her aid to be called in. The ideas of the early navigators on the subject of the longitudes of the ports they visited were, in many cases, almost absurdly incorrect, judging from present knowledge.

The reason for this uncertainty about longitude is simple. Longitude can only be measured by connecting it in some way with the Earth's rotation, and if we neglect the motion of the Sun among the stars, it is not difficult to understand that it is the angle through which the Earth must rotate in order that the Sun may pass from the meridian of Greenwich to that of the place, or *vice versa*. It is, in fact, the difference between the hour angle of the Sun at the place of observation, and at Greenwich; or in other words, the difference between local and Greenwich time. Longitude is often expressed in terms of time, allowing twenty-four hours to the 360 degrees, or one hour to 15 degrees. (One minute of longitude is thus equivalent to four seconds of time.)

Now there is no difficulty in finding, from an altitude of the Sun, by means of appropriate formulae for computation, the local time at the place of observation, provided the latitude is known with sufficient accuracy—this is necessary, since the latitude enters into the formulae used—but we have seen that the determination of latitude is not a very difficult matter, given suitable objects on or near to the meridian—so that if we have any means of knowing the *Greenwich* time at the moment of the observation we have at once, by taking the difference between the two times, the longitude of the place expressed in hours, etc., which can be converted into degrees, etc., by multiplying by fifteen. For the determination of local time it is essential to use an object as far from the meridian as possible, so that the change of its altitude may be as rapid as possible: in fact the conditions for the determination of local time (and longitude) are just the reverse of those desirable for the determination of latitude. The latitude used in the determination of local time cannot of course be obtained from the *same* observation; we must find it from an object on or near the meridian.

The great difficulty, however, as regards the determination of longitude was the fact that there was no reliable method known of finding the Greenwich time of the observation. Clocks indeed were in use on land, but even these were of very second-rate accuracy compared to those of the present day, while at sea of course anything with a pendulum is absolutely useless. It was therefore necessary to look about for some indication of Greenwich time which would be available all over the world;

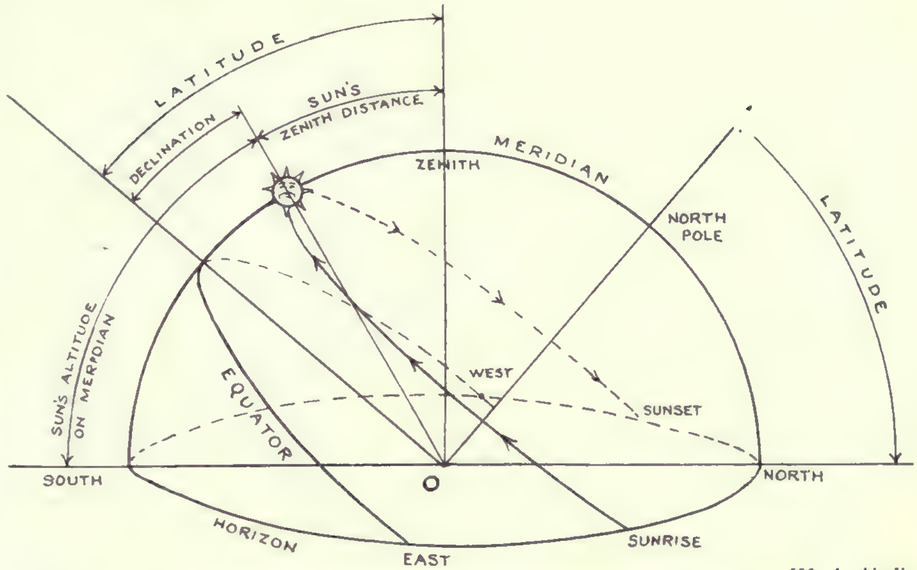


[*M. A. Ainslie.*

CORRECTION FOR PARALLAX.

For most purposes the diameter of the Earth can be neglected in comparison with the distance of a celestial object; but for near objects—Sun, Moon, and the planets Venus and Mars when near the Earth—a small correction has to be *added* to the observed altitude to allow for the size of the Earth. In the diagram this correction is the difference of the angles SOL and SCM, or the angle COS or SOR.

and in the year 1514 we find the first suggestion of the use of the Moon for the purpose. The motion of the Moon among the stars is much more rapid than that of any other celestial body: on an average she covers her own diameter in something like fifty-nine minutes. It is obviously possible to employ the Moon as the hand of a great celestial clock, the stars, Sun, and planets, being the marks on the dial. Assuming that the motion of the Moon is sufficiently well observed and understood to enable her position among the stars to be accurately predicted, there would be no difficulty in obtaining the Greenwich time at any moment by observing her distance from one or more stars (or Sun and planets) and comparing the observed distance with that predicted for certain specified Greenwich times. But at that time the motions of the Moon were not understood with anything like the necessary accuracy; and it was not until after the middle of the Seventeenth Century that this method of obtaining Greenwich time was seriously considered. It was for the express purpose of improving the theory of the lunar motions, for the benefit of navigation, that Greenwich Observatory was founded in 1675 by Charles II.



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LATITUDE BY MERIDIAN ALTITUDE OF THE SUN.

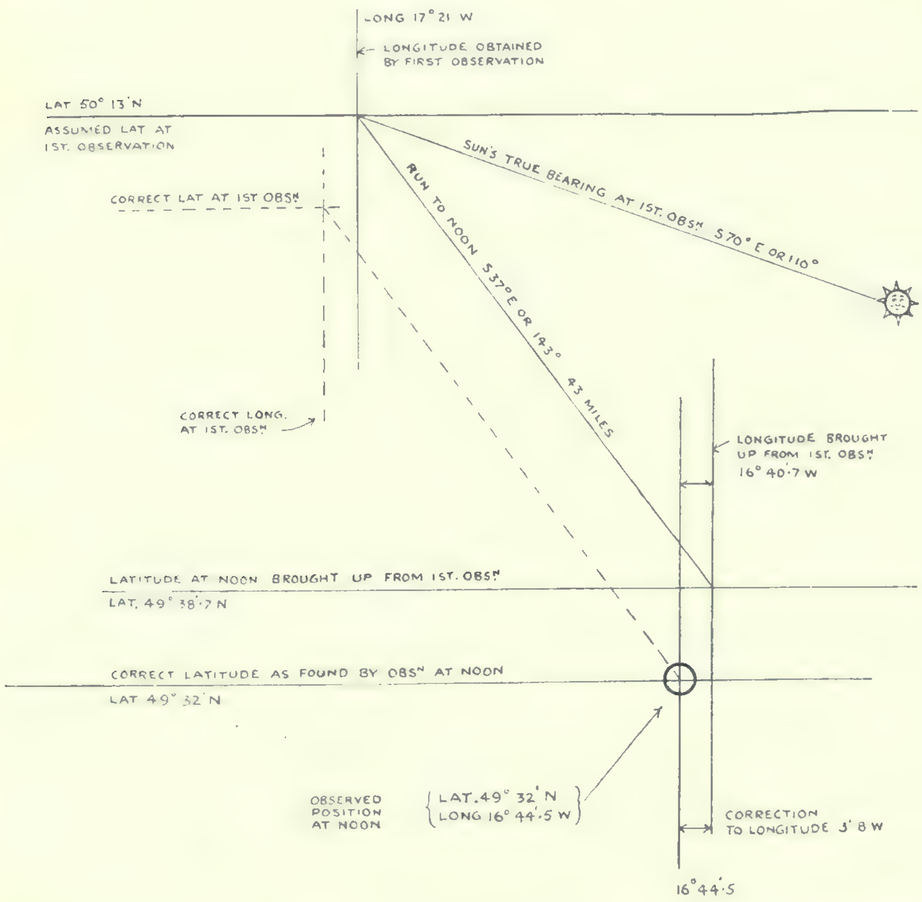
The diagram shows the relative position of pole, equator, etc., for a place in north latitude, the Sun being north of the equator: *i.e.*, in summer. The diurnal path of the Sun from sunrise to sunset is also shown. It will be seen that the latitude is in this case the sum of the declination and meridian zenith distance: ZOQ and PON are equal since POQ and ZON are both right angles.

Other methods of obtaining Greenwich time had in the meanwhile been suggested; the eclipses and occultations of Jupiter's satellites, for example, are phenomena for which the Greenwich time can be predicted with considerable accuracy, and, given a telescope of suitable power, it might (in theory) be possible to observe them at any time when Jupiter is above the horizon, and when—though this is not so frequent as might be desired—such phenomena are taking place. This method, however, has never proved of any utility, for two reasons: the phenomena in question are anything but instantaneous, and at the best the time deduced from them would be uncertain; and no telescope of sufficient power to render them easily visible could for a moment be used at sea. This method therefore is of purely theoretical interest, and—as far as the present writer is aware—has never been usefully employed.

In practice, up to the latter part of the Eighteenth Century, the observation of "lunar distances" was the standard, and indeed, the only method by which longitude could be determined; and though the observation with a sextant of the angular distance of the Moon from the Sun or a star or planet is by no means easy to carry out with the requisite accuracy, and the computations necessary to obtain the longitude are long and laborious, even with the assistance of special tables, the results obtained were not by any means to be despised. A practised observer with a good sextant could generally depend on his longitude thus found to within fifteen minutes or so, and the mean of several observations often gave a result correct to within two or three minutes. But the necessity for the "Lunar" was soon to disappear. In 1761 Harrison produced the first practical chronometer, and navigators could for the first time "carry the time with them"; and although lunars were for many years to retain their

place among standard methods, and in the education of the officers of the Royal Navy and of the Mercantile Marine, the steady improvement of the chronometer in the hands of Arnold, Earnshaw, and others soon increased, beyond anything that had been hoped for, the accuracy of longitude determination at sea.

We have now briefly discussed the most simple ways in which latitude and longitude can be determined: the former by a meridian altitude of the Sun or other celestial object, and the latter by an altitude well away from the meridian, the Greenwich time of the observation being noted by means of the chronometer, and the local time calculated from the observed altitude. Let us now see how the position of the ship would in practice be determined. In general, of course, the ship is not at rest between the two observations; but its "run between sights" may be determined with fair accuracy by means of the compass and log line, due allowance being made for winds and currents so far as their effects can be gauged. The procedure in a simple case would be somewhat as follows:—



[*M. A. Ainslie.*

WORKING THE LONGITUDE UP TO NOON.

This illustrates the simplest astronomical method of fixing the ship's position at noon; the dotted lines indicate the method of obtaining the longitude from the first observation by working the correct latitude back from noon. It is not usual, however, to wait until the noon latitude is known before working the earlier observation, and the latter is worked, as a rule, with an assumed latitude, and a correction to the longitude afterwards applied when the true latitude is known.

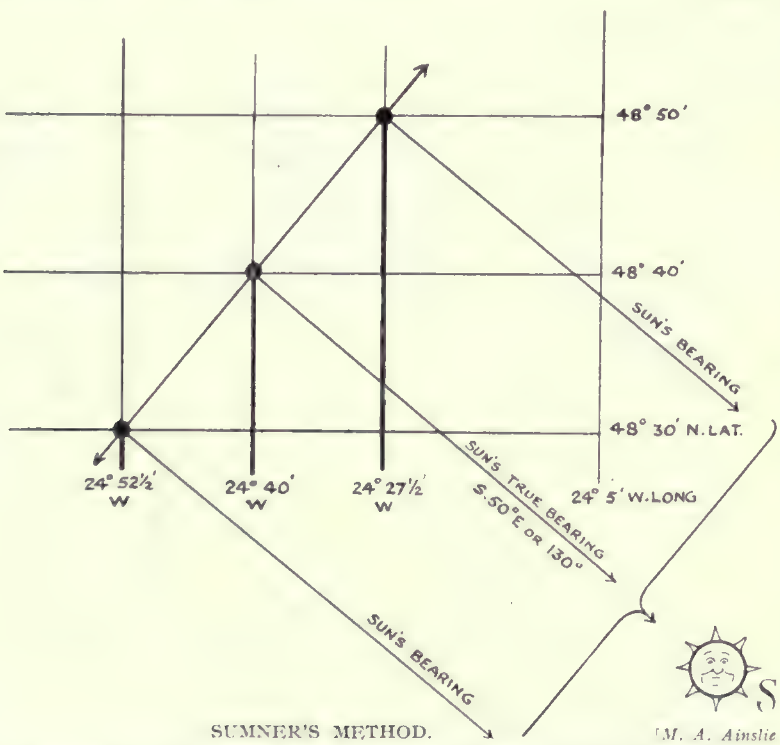
The navigating officer, armed with his sextant, and accompanied by an assistant with a watch which has been recently compared with the chronometers (as a rule three in number) so that its error on Greenwich Mean Time is known, observes the altitude of the Sun some three or four hours before noon. When he has made a good "contact," *i.e.*, when he has got the image of the Sun just to touch the horizon as seen in the telescope of his sextant, he calls "stop" to his assistant, who notes down the time and the altitude as read on the arc of the sextant; this operation is repeated three or more times, and the mean of altitudes and times taken. The altitude as read on the sextant has then to be corrected for various errors. First there is the "index-error" of the sextant; this is due to the index, or vernier, not exactly reading zero when the mirrors are parallel, and as it is fairly constant, and can

easily be determined at any time, no great trouble is so far caused. Next there is the fact, to be allowed for, that the Earth is a globe, and that the observer's eye is raised—sometimes considerably—above its surface. The effect of this is that the observer sees the horizon, apparently, below its proper position, so that his altitude as observed is somewhat too great. This correction is tabulated; its value, in minutes of arc, happens to be slightly less than the square root of the height of the observer's eye above the sea in feet. Next an allowance has to be made for the refraction of the rays of light from the Sun caused by the Earth's atmosphere. This refraction has the effect of slightly raising the apparent place of the Sun in the sky, so that the correction, which is obtained from tables, has to be subtracted. Next, in the case of the Sun and Moon, a correction has to be made for what is called "parallax"; the mathematical calculation required to obtain the local time of the observation is based on the assumption that the diameter of the Earth may be neglected, *i.e.*, that the observation is made from the Earth's centre instead of from its surface. This involves an additive correction which, in the case of the Sun, never exceeds 8·8 seconds, but in the case of the Moon, may be as great as a whole degree. For planets—with the possible exception of Mars and Venus when they are near the Earth—this correction is usually unnecessary, while for stars it is, of course, utterly inappreciable. Lastly, when

Photo by] [*M. A. Ainslie.*

"SHOOTING THE SUN." MIDSHIPMEN, R.N., TAKING OBSERVATIONS FOR POSITION.

Daily practice in fixing the ship's position by astronomical observations forms an important part of the instruction of Midshipmen afloat. Here a class is taking the Sun's altitude on the meridian, from the quarter-deck of a battleship of twenty-five years ago.

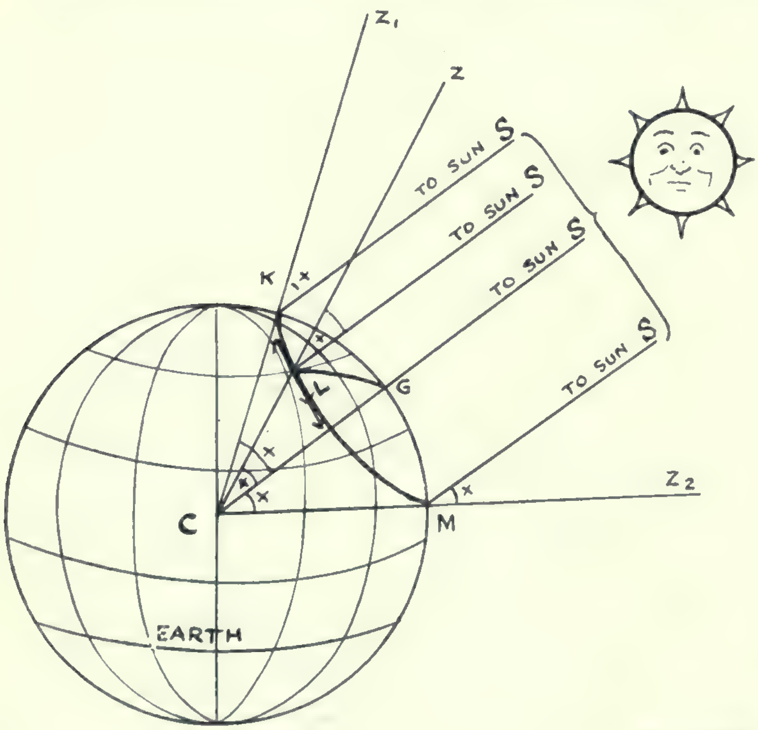


SUMNER'S METHOD. [*M. A. Ainslie*

An observation for longitude worked with three different assumed latitudes will, in general, give three different results, which indicate points on the chart lying approximately on a straight line (actually on a circle of very great radius). This line is called a "position line," and the ship must be somewhere on it. The position line is at right angles to the Sun's bearing, which is practically the same at each of the three points. Of course, only two points are really necessary to define the position line, but three are here shown to illustrate the principle. This is Sumner's original method, and gives a *chord* of the circle of position. In the more modern method a *tangent* to this circle is obtained, but the difference is inappreciable.

the Sun or Moon is observed, account must be taken of the fact that it is always the limb which is observed (usually the lower limb in the case of the Sun) and not the centre of the disc ; a correction therefore has to be made, either additive or subtractive, for " semi-diameter," which amounts to about fifteen minutes. Convenient tables are provided for Sun and stars by which all these corrections (except, of course, that for index-error, which depends on the sextant in use) can be applied as one quantity ; the case of the Moon requires rather more work, since the parallax and semi-diameter vary with great rapidity, depending on the Greenwich time of the observation. The computation then proceeds as follows : the Sun's true altitude being known, it is subtracted from ninety degrees to give the true zenith distance. A latitude is now *assumed*, as near to the truth as can be deduced from the ship's run since the last observations, allowance being made for currents, etc., as far as possible. With this assumed latitude, the true zenith distance, and the declination of the Sun, taken from the Nautical Almanac, and corrected for the Greenwich time of observation, a computation is made by the formulae of Spherical Trigonometry, resulting in the Sun's hour angle, commonly called " Ship Apparent Time," or " S.A.T." The " Equation of Time "—obtained from the Nautical Almanac like the declination, and corrected in the same manner—is now applied, and we have the " S.M.T." or " Ship Mean Time." The difference between this and the " G.M.T." (known from the time by the watch) is converted into degrees, etc., and the result is the longitude.

The assumed latitude, combined with the longitude found from the observation, gives a fresh starting point, and the ship's run to noon is either worked out or laid off on the chart. A few minutes before noon the navigator sets his sextant to what he knows will be approximately the Sun's altitude at noon, and as before, he " makes contact " of the Sun's limb with the horizon. The Sun's altitude near noon increases very slowly, and he follows it by making contact from time to time, until the altitude is a maximum : this he takes to be the meridian altitude ; he corrects this as before, applies the declination, and the result is the " latitude by mer. alt." at noon. This will in general differ from the latitude at noon found by working up the ship's run from the assumed latitude at the earlier observation ; this indicates that his longitude is also in error, for it will be remembered that the assumed latitude entered into the calculations for the longitude. He now either works back from the true noon latitude and finds the true latitude at the time of the first observation, and reworks the



[*M. A. Ainslie.*

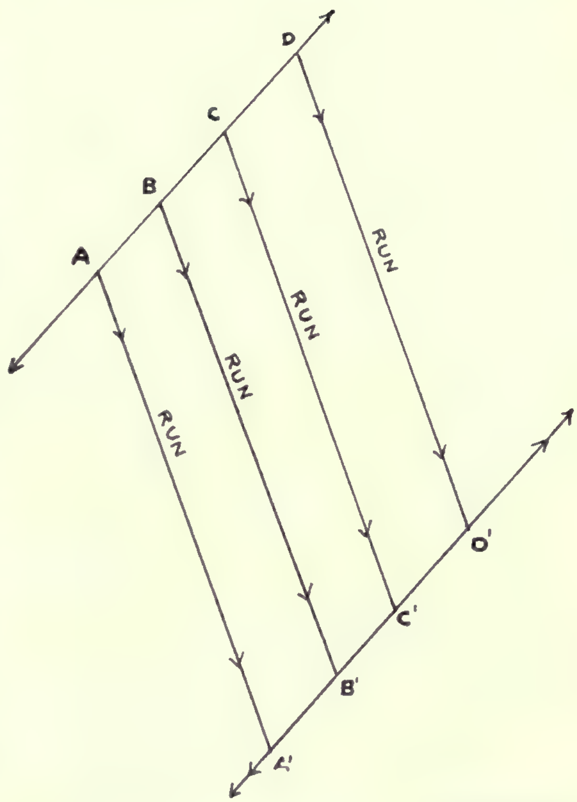
THE CIRCLE OF POSITION.

K, L, M, are three places on the Earth's surface at which the Sun's zenith distance is the same. This zenith distance is indicated by any of the angles marked in the diagram, and may be measured by the arcs KG, LG, MG, G being the " geographical position," or point where the Sun is in the zenith. Therefore, K, L, M, all lie on a circle whose centre is G and whose radius is the arc KG, which is the zenith distance common to the three points. Any other place at which the Sun has the same zenith distance must lie on the same circle ; so that a single observation locates the ship somewhere on this circle, and we can draw a small part of the circle in our immediate vicinity by finding one point on it—such as L—and drawing a tangent to the circle, which practically coincides with the circle for a short distance, say 30 or 40 miles.

longitude with this true latitude, then bringing the longitude forwards (by the ship's run) to noon ; or he applies a correction to the longitude which is found by convenient tables, and which depends on the Sun's true bearing at the time of the first observation, which is itself found either by calculation or by Azimuth Tables specially constructed for this purpose. This is the more usual method. Of course if the navigator is not anxious about his longitude at the time of the first observation, he may defer the working of the first observation until he knows the true latitude ; but this is in general not desirable, unless the ship is well clear of any possible danger.

To recapitulate : the first observation is taken some hours before noon, when the Sun is well away from the meridian, and worked (with an assumed latitude) for longitude. This latitude and longitude are brought up to noon ; the true latitude is found by observation at noon ; and a correction is applied to longitude for the error in the assumed latitude.

The above may be called the straightforward, " classical " method, and is the simplest way of finding the position at noon ; but modifications have to be introduced if, for example, the Sun is not visible at noon, or the position is required before noon with regard to some possible danger ; in fact the variations on this method, as well as the modifications introduced by the use of Moon or stars, are endless and cannot be here detailed. They all, however, have this in common : two observations at least are required, either simultaneous or separated by an interval during which the ship's run must be allowed for ; and as a rule, one observation is worked for latitude and the other for longitude.



[*M. A. Ainslie.*

TRANSFERRING POSITION LINE FOR RUN OF SHIP.

A, B, C, D, all lie on the position line obtained by an observation, and are all therefore *possible* positions of the ship at the time of the observation. If the ship's run is laid off on the chart from each of these in turn, points A′, B′, C′, D′ will be obtained which are all possible positions after this run. These lie on a straight line parallel to the original position line, so that the new position line might be found by laying off the run from any point on AD, and drawing A′ D′ parallel to AD through the point thus obtained.

We may now pass on to the great development of astronomical methods in navigation due to the conception of " Lines of Position," and usually associated with the name of Sumner, though it seems to have occurred to many astronomers and navigators as well. However, Sumner's enunciation of the principle may very well be taken as an illustration. Sumner's was at any rate the first published account of the principle, though at a still earlier period it appears to have been employed, both in the Royal Navy, and by others.

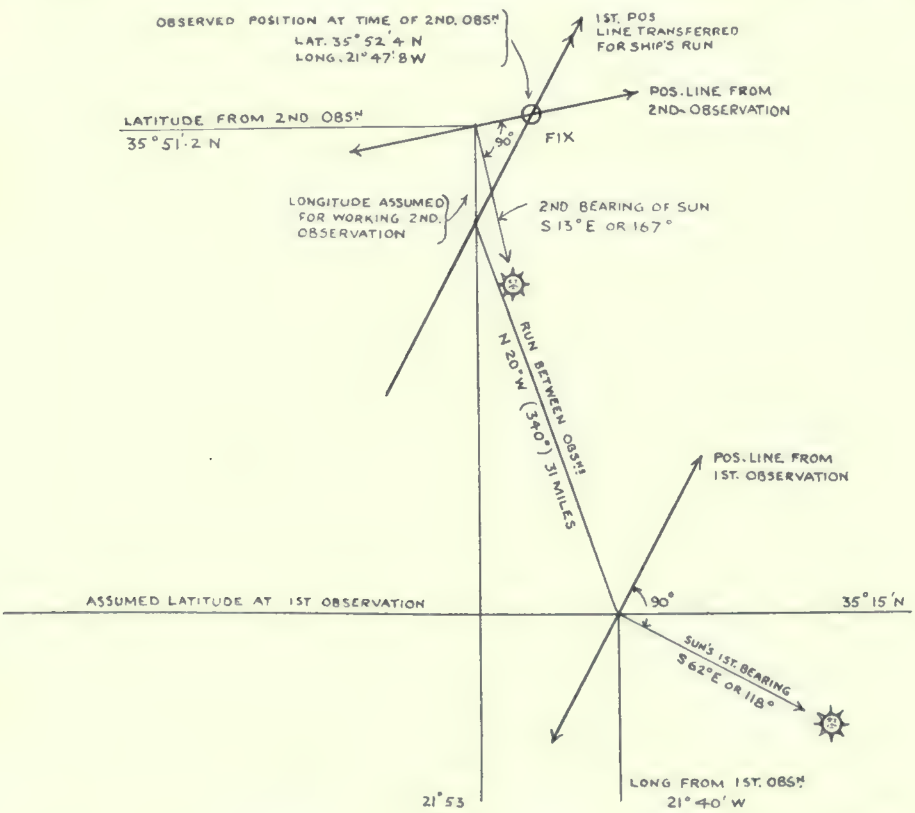
Capt. Thomas Sumner, of the U.S.A. Mercantile Marine, was, in or about the year 1846, making a passage from the U.S.A. to London, and on nearing the S.W. coast of Ireland his position was uncertain owing to several days having elapsed without observations of the Sun. On the sky clearing, he obtained an altitude of the Sun in the forenoon, its bearing being somewhat to the south of east. A latitude was assumed, and the resulting longitude worked out, a point on the chart being thus indicated on the assumed parallel of latitude. As there was considerable uncertainty as to the latitude, the longitude was again worked with a different assumed latitude, and a fresh point on the chart obtained ; a third assumed latitude was taken and a third point obtained. It was then noticed that

the three points obtained lay on a straight line, and that this straight line passed through the position of the Fastnet Rock. On working the observation once more with the latitude of the Fastnet, the longitude of the Fastnet was obtained ; and he inferred that *the observed altitude must have occurred at the same instant at all points on this straight line, and, further, that this straight line was at right-angles to the Sun's bearing.* It followed that at the time of observation the ship must have been *somewhere on this straight line.* Whether or not Capt. Sumner realised the principle (presently to be described) of the " Circle of Position," he had at any rate discovered a method of making use of his observation, even though his latitude at the time might have been quite uncertain.

The basic principle of " Position Lines " may now be explained, and it will do no harm if we take a homely illustration at the outset.

Suppose a bandstand in some public gardens, surmounted by a brilliant electric light, and surrounded by chairs placed in circles with the bandstand as the centre. An observer who took the trouble to observe the angular altitude of the light (*i.e.*, its " angle of elevation ") with suitable instruments from the chair which he occupied would, it is fairly evident, obtain the same result if he moved to any other chair in the same circle ; further, he might, if he were to record the altitude of the light as he observed it, identify the circle in which he was sitting at some future time, by noting which of the circles gave the proper altitude to the light ; the observed altitude, in short, would locate him on a particular circle. Further, the direction of the part of the circle in his immediate neighbourhood would be at right angles to the direction in which he saw the light.

The step from this terrestrial illustration to the celestial conditions is a short one. For " electric light " read " the Sun or other celestial object " ; let the chair turn into a ship of which the observer is the navigator ; then an altitude of a celestial object locates the ship on a certain circle on the Earth's surface, and the direc-

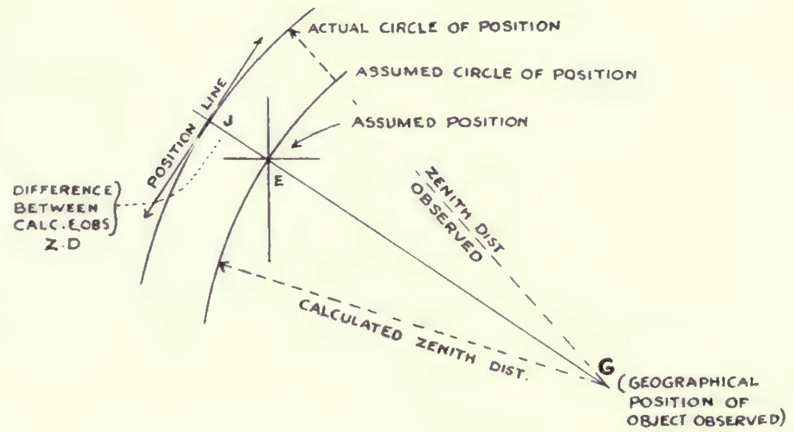


[*M. A. Ainslie.*

COMBINATION OF TWO POSITION LINES.

The first observation is worked for longitude, a latitude being assumed ; the resulting longitude brought up (by applying the run) to the time of the second observation, which in this case is near the meridian and is worked for latitude. The position line in each case is at right angles to the Sun's bearing at the moment of observation, which is obtained from tables. Although the first observation does not give a correct longitude, nor the second a correct latitude, the resulting position lines are correct, so that the intersection of the second position line with the transferred first position line is the true ship's position at the time of the second observation. Until the introduction of Marcq. St. Hilaire's method this was the standard method of finding the ship's position, and it is still very commonly used.

tion of that part of the circle in the immediate vicinity of the ship is at right angles to the bearing of the celestial object. The centre of the bandstand becomes the point on the Earth's surface which has the celestial object in its zenith ; and this is called the "Geographical Position" of the celestial object, and sometimes the "Sub-solar Point."



[*M. A. Ainslie.*

PRINCIPLE OF MARCQ. ST. HILAIRE'S METHOD.

Here the zenith distance calculated for the assumed position is *less* than that observed ; so the difference is laid off along the line of the Sun's bearing, *away* from the geographical position, and the position line, which is a tangent to the circle of position, is drawn through the point thus obtained, at right angles to the line of bearing. If the *calculated* Z.D. were the *greater*, the difference would be measured in the opposite direction, *i.e.*, towards the geographical position.

If the observer could stop the rotation of the Earth, so as to keep the geographical position of the object fixed, and travel towards this point, he would find the altitude of the object increase by one degree for every sixty nautical miles he travelled (a nautical mile, it will be remembered, is the value on the Earth's surface of a minute of angle at the centre), so that his distance from the geographical position is the number of minutes in the zenith distance of the body. In all practical cases this distance is very great ; for example, if the altitude of the object were seventy degrees it would be 1,200 nautical miles ; so in his immediate vicinity he would make no serious error if he considered his circle as a straight line—if, to put it in another way, he used the tangent to the circle instead of the circle itself.

Now in any practical case the bearing or direction of the object (or its geographical position, which is the point vertically beneath it) would not alter much from point to point of the circle, provided we do not go more than, say, thirty or forty miles ; so a rough knowledge of the ship's position is quite sufficient to enable us to calculate the bearing of the object at any moment of Greenwich time, that is, to calculate the direction of the tangent to the "circle of position." This tangent is called the "Position Line." We know its direction ; if we can find one point on it we can draw it on the chart. This point may be found, either by assuming a latitude and working the observation to give the corresponding longitude, or *vice versa*, according to the bearing of the object ; if near the meridian we work for latitude, and if well away from it, for longitude. In either case the point thus found is marked on the chart, and a straight line drawn through it at right angles to the bearing of the object ; this is the line of position, and the observation has given us the valuable information that we must be somewhere on this line, although it does not tell us where.

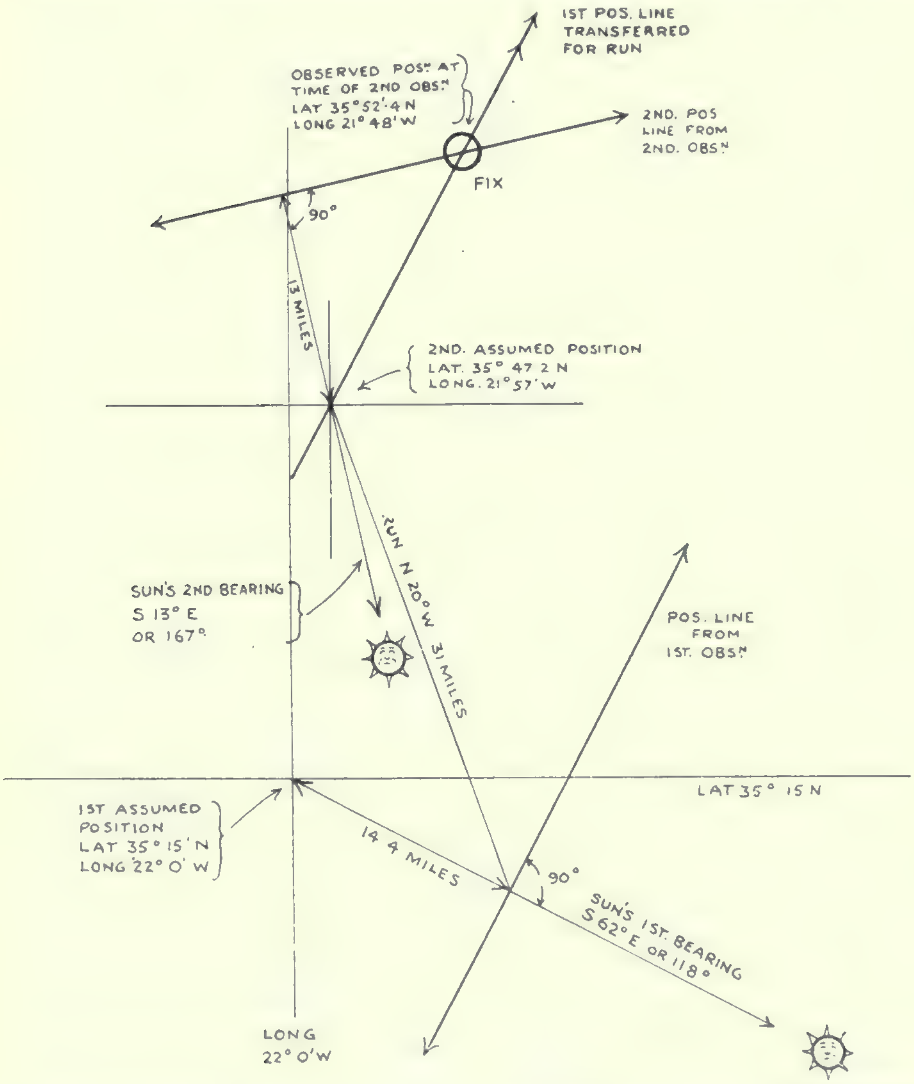
But if we can, either from an observation of another object at the same time, or of the same object after it has had time to change its bearing considerably, obtain another "line of position," we must evidently be at the intersection of the two lines ; so the ship's position is finally determined.

We have, however, so far assumed the ship at rest between the observations ; but the motion of the ship is easily allowed for. All we have to do is to take any point on the position line obtained from the first observation, and to lay off from it on the chart the ship's run in the interval between the observations ; this will give us another point which, it is true, may not be the actual position of the ship, but which is at least a possible position. Any number of possible positions might thus be obtained by starting from different points on the first position line, and they would evidently all lie on a straight line parallel to the first position line ; so the simplest thing to do is, to draw a straight line through the new point parallel to the original direction of the position line, and this is our position line at the time

of the *second* observation, as determined by the *first*. The position line obtained from the second observation crosses this at the ship's position.

It will thus be seen that even if only one observation is obtained, something is known about the ship's position ; namely, that she is on a certain straight line on the chart. This information may be made of service at a time considerably after the observation, for this line, as we have just seen, may at any time—say two or three hours later—be utilised, being moved about the chart according to the ship's run in the interval. The advantage of such a line of position, especially near land, is very great ; for example, if it is parallel, or nearly so, to the coast-line, it tells us at once how far the ship is from land. If it passes near some danger, it shows how we must steer to avoid that danger; in fact, it is very often almost as useful as would be a precise determination of the ship's position.

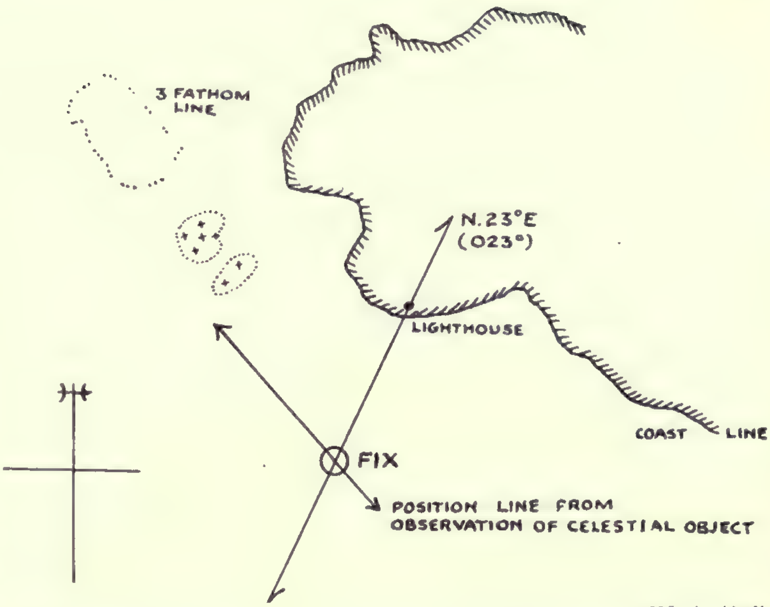
So far we have confined ourselves more or less to the determination of latitude or longitude *as such* from the altitude of a celestial object ; and it was mentioned above that latitude observations had to be taken on or near to the meridian, and longitude observations as far from it as possible. Many navigators have therefore assumed that if an object is too far from the meridian for latitude observations, and too near it to give the longitude, it was of little use to observe it at all, and much valuable information has thus often been missed. We have now to consider the very valuable general method known as " Marcq. St. Hilaire's," after the French Naval Officer who suggested it many years ago—though its general adoption as the standard method in the Royal Navy is



[*M. A. Ainslie.*

POSITION BY MARCQ. ST. HILAIRE'S METHOD.

For this illustration the same observations were used as for that on page 830 (the older method). Here the zenith distance observed was 14·4 minutes *less* than that calculated, at the time of the first observation, and thirteen minutes *greater* at the time of the second. Had other positions been assumed, these values would have been different, but the same position lines would have been obtained, and therefore the same final position.



[*M. A. Ainslie.*

USE OF A SINGLE POSITION LINE. COMBINATION OF AN ASTRONOMICAL POSITION LINE WITH A BEARING OF A TERRESTRIAL OBJECT.

Even if the bearing of the lighthouse had not been obtained (by compass), the position of the ship would be known to be somewhere on the astronomical position line shown, and it would only be necessary to steer along the position line to pass clear of the rocks and three-fathom patch. The additional fact that the bearing of the light was N.23° E. serves to fix the position completely.

of quite recent date, and in the Merchant Service it has, even at the present time, been to a great extent neglected.

Marcq. St. Hilaire's method is what might be termed a "trial and error" method. Suppose we assume some position for the ship, which is known to be not far from the truth, say within thirty or forty miles. The altitude and chronometer time are as usual taken, and the corrections (described above) applied to the observed altitude, the true zenith distance being deduced.

Now suppose that we compute, from the Greenwich time as given by the chronometer, and the position assumed, the zenith distance of the object. If this is the same as that found by observation, then the position line must pass through the assumed position, and as we know its direction from the bearing of the object, we can draw it at once. But in general the zenith distances, calculated and observed, will differ. To take a numerical example, suppose that the assumed position is 50° N. lat. and 12° W. long., that the zenith distance calculated from this position is 35° 17′, and that as observed it was found to be 35° 23′. We know therefore that the assumed position is distant from the geographical position of the object by the number of minutes in 35° 17′, *i.e.*, 2,117 miles. Similarly, we know that the ship's distance from the G.P. is 2,123 miles, *i.e.*, 6 miles more. That is, the radii of the two circles struck from the G.P. as centre and passing through the assumed position and the actual position respectively, differ by 6 miles, the circle through the actual position having the greater radius. We are, in fact, 6 miles farther from the G.P. than we thought. Suppose now that the bearing of the object, as obtained from the tables for the assumed position, is 43° west of south, or "S. 43° W." Draw a line on the chart through the assumed position away from the G.P., *i.e.*, in the direction N. 43° E.; this will be a radius of the two circles just mentioned. Measure 6 miles along this radius, *i.e.*, away from the G.P., or N. 43° E.; this brings us to a point on the actual circle of position on which the ship is situated. Draw a tangent to the circle of position through this point, *i.e.*, running from N. 47° W. to S. 47° E.; this is the required position line, which may as before be moved about the chart according to the course and speed of the ship. If the observed zenith distance had proved to be the smaller, of course the difference would have been measured the other way, or towards the G.P. To obtain the actual position of the ship, we can as before obtain another position line, either from another object or from the same object (in the case of the Sun) after an interval; the intersection of the two position lines gives the "Fix," or final position.

The advantages of this method are considerable. The navigator need no longer worry as to whether an object is suitable for the determination of latitude or longitude; any object, no matter what its position in the sky, will give a reliable position line, assuming of course that the horizon is clearly visible; and all observations are worked by the same formula. It will be noticed that this method dces not

give the latitude and longitude as such; but it enables us to do what is in general far more important, namely, to mark on the chart the ship's position relative to any possible dangers; the latitude and longitude, if it is desired to record them, can be easily measured from the chart.

When two position lines are thus combined to give the ship's position, it is important that the angle between them should be as nearly as possible a right angle; certainly not less than fifty degrees if it can be avoided, though of course very often the navigator has to take what he can get. The position line is best regarded, not as a mathematical straight line, but as a band which may, according to weather conditions, clearness of horizon, etc., be one or two miles in width; the intersection of two position lines cannot be considered as an accurately-determined point, but should be regarded as a parallelogram, inside which the ship is probably situated. A prudent navigator would always take that point in the parallelogram, which seemed to put his ship nearest to a possible danger, as his "fix." It will be seen, if the reader will draw a few examples, that the length of the parallelogram may be several miles, if the angle between position lines is small—if the "cut" is bad. Under the best possible conditions, with a right angle between the lines—a "ninety degrees cut"—the parallelogram is a square, or a rectangle if the one observation is considered more reliable than the other. When possible, a third or even a fourth position line should be obtained, to give greater certainty.

The width of the "position band"—to coin an expression for it—is due to several causes; instrumental errors of the sextant, want of clearness and sharpness of the horizon, and uncertainty as to the error of the chronometer, are obvious causes of inaccuracy, though the last, in these days of wireless time signals, is usually negligible. But the most serious cause of uncertainty, though happily uncommon, is abnormal displacement of the apparent horizon. Instances of this, which appears to be due to peculiar and often unsuspected conditions of temperature of air and sea, have been recorded to the extent of eighteen miles; and on one occasion when at anchor a few miles west of Portland, the writer, together with several of his pupils—all capable observers—obtained, on an apparently normal fine summer's day, a position for the ship more than three miles inland! Little is known even now as to the causes and amount of this displacement; but it must always be considered a possibility.

Photo by] [*M. A. Ainslie.*

FINDING THE TIME BY OBSERVATIONS WITH SEXTANT AND ARTIFICIAL HORIZON.

Observations for time with the artificial horizon form part of the series of observations sent in by Midshipmen, Royal Navy, to qualify for the rank of Lieutenant. The observer is here seen on the right, viewing the Sun's image as reflected in a trough of mercury, protected from wind by a glass roof. His assistant is noting the time at which he "makes contact" of the two images, by means of a chronometer (the latter hidden in the photograph by his right foot). The angle observed on the sextant is in this case about 120°.

Before leaving the subject of position lines, it should be mentioned that a very excellent position may often be obtained by combining an astronomical position line from a celestial object with a line of bearing of a point on land. When approaching land, for example, a position line may be obtained from a celestial object and moved along with the ship; if a light is then sighted and its bearing taken by compass, the line of bearing drawn on the chart will by its intersection with the previous position line at once give the fix, often with great accuracy.

The application of Astronomy to Navigation is by no means confined to the determination of a ship's position. The azimuth, or true bearing,

of a celestial object can always be obtained from the chronometer time or from its altitude; this can be compared with the bearing by compass, and the all-important error of the compass can be thus readily determined. Again, before the days of wireless time signals, the error of the chronometer had to be inferred from its error as determined by a time-ball or other signal on shore, and its (previously determined) daily rate—or amount lost or gained per day. The daily rate of even the best chronometer is subject to alteration; and in consequence, after long absence from any source of correct time, the uncertainty in its error might amount to several seconds. If, however, the navigator lands at some spot of which the position is well determined, he can observe the Sun's altitude by reflection in a trough of mercury (commonly known as an "artificial horizon") and deduce the Greenwich Mean Time from his observation, so obtaining a fresh determination of the error and rate of his chronometer. The necessity for such observations, however, has practically disappeared with the advent of wireless time signals; even a good watch, constantly checked by these, will usually serve all the purposes of the navigator, so far as determination of positions is concerned. For surveying purposes, however, observations with the artificial horizon—which are far more accurate than those obtained at sea—are of great use in fixing the positions of points on shore, islands, etc., the Greenwich time being known by wireless signals.

Photo by] [*M. A. Ainslie.*

TAKING THE COMPASS BEARING OF THE SUN WITH THE KELVIN AZIMUTH PRISM.

The Navigating Officer is observing the Sun by means of a prism mounted on the compass, and so arranged that by means of a simple optical system he sees the image projected on the divided circle of the compass card. By computation of the Sun's true bearing from the time (or altitude) the error of the compass is thus obtained. In front of the compass is seen one of the soft iron spheres used to correct the compass error due to the soft iron of the ship.

CHAPTER XXIV.

CHARTS AND NOTES FOR OBSERVERS.

PART I.—A MODERN MAP OF THE MOON.

By W. Goodacre, F.R.A.S.,
President of the British Astronomical Association.

ON the following pages will be found a reduced copy of this Map in 25 sections.

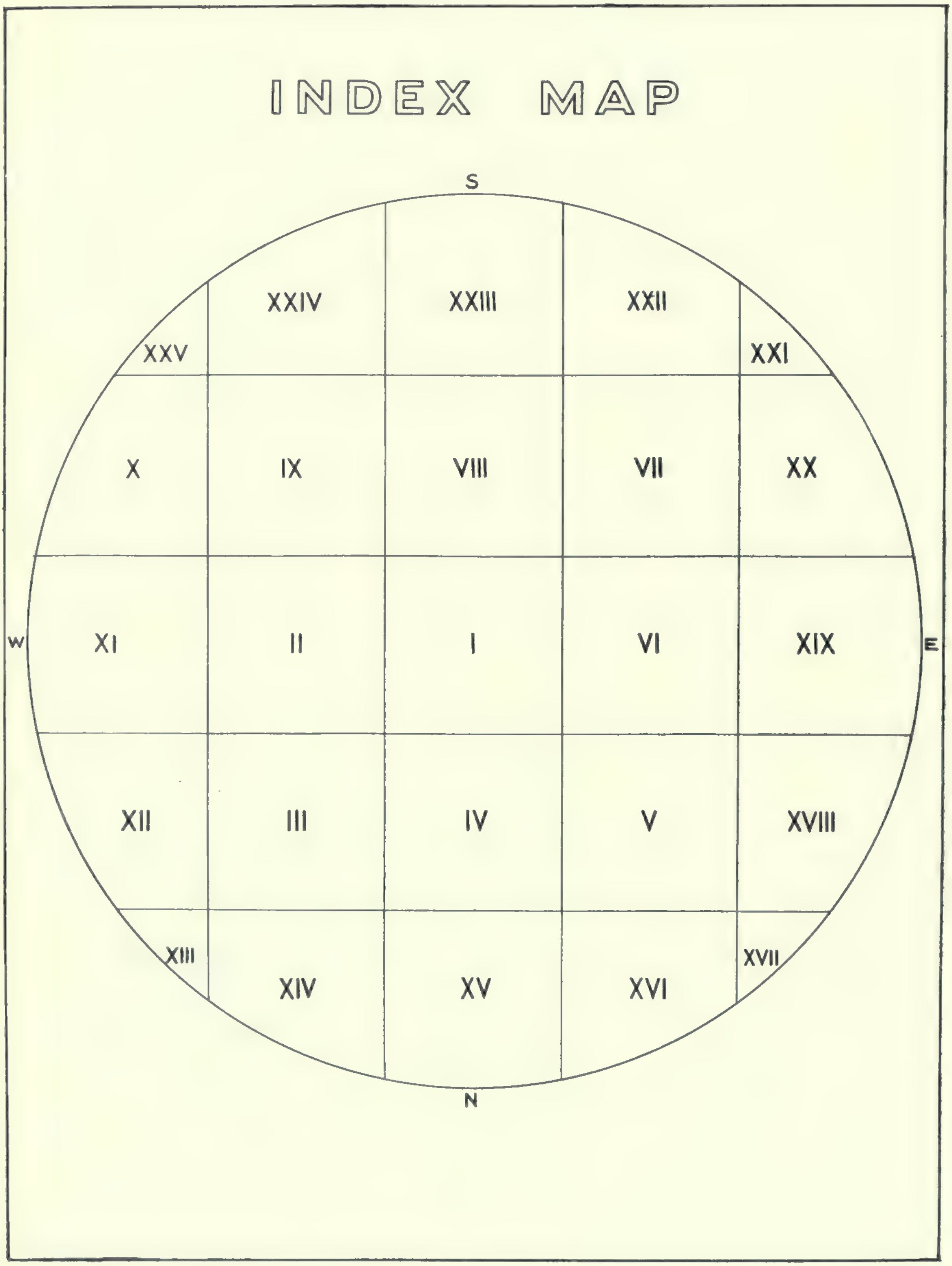
The original Map was drawn on a single sheet 77 inches in diameter, afterwards reproduced in 1910 in 25 sections on a scale of 60 inches to the Moon's diameter. These 25 sections are now further reduced to meet the exigencies of the space available.

The Map has recently been revised and brought up to date, and is now the best in existence available for students of the Moon's surface.

The number of named formations is 522.

The limited space available has not allowed of more than the briefest description of the same. In those sections where the surface is very crowded with craterlike formations, reference to some of those of little importance has been omitted.

All the coarser details on the maps are visible in comparatively small telescopes, but much of the finer detail, such as craterlets and some of the delicate clefts, can only be seen by the use of large telescopes under good conditions.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SECTION I.

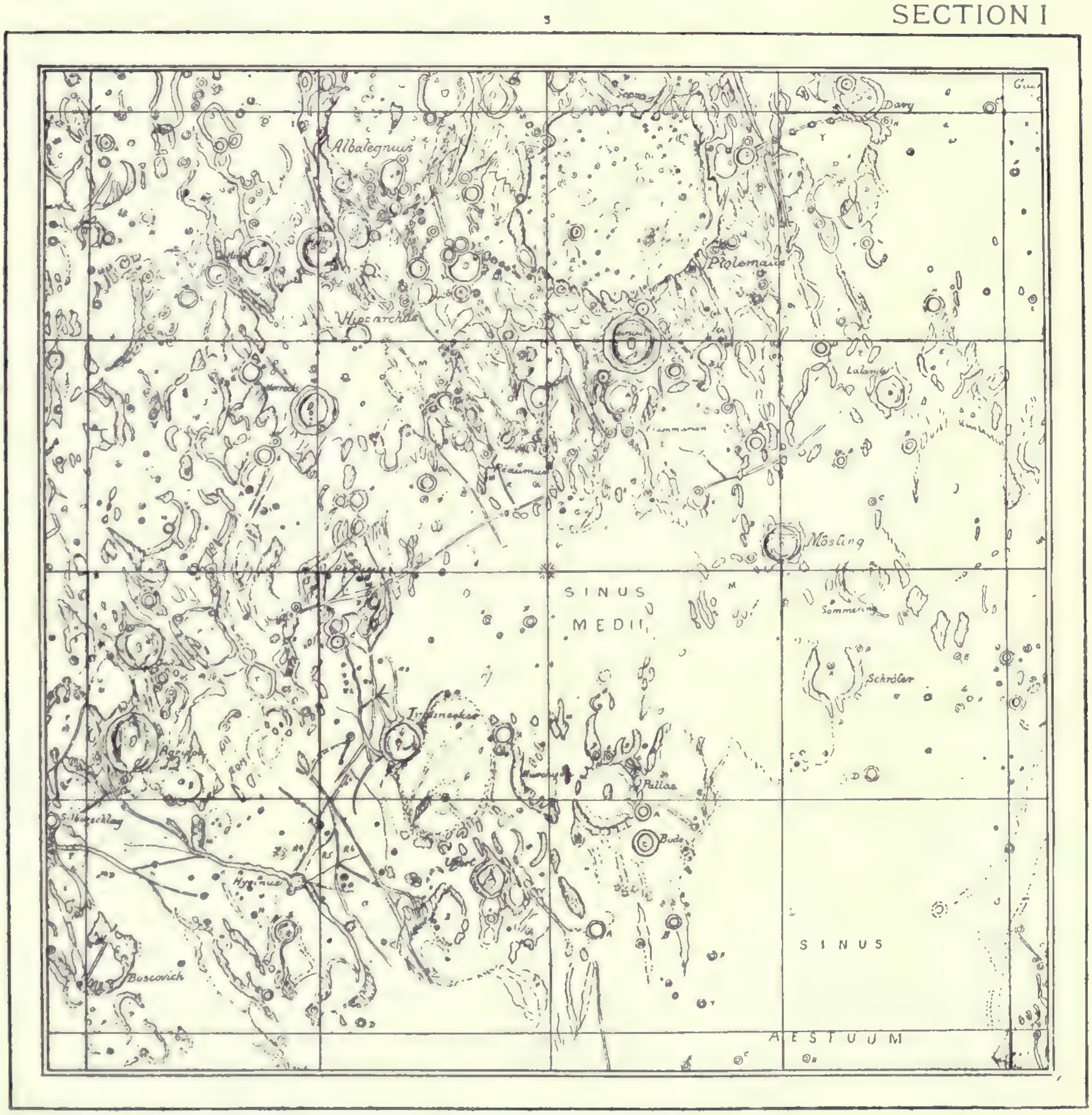
Agrippa. A Ring Plain 28 miles in diameter with bright steep terrace walls rising 7,000 to 8,000 feet above the interior.

At the centre is a bright central peak—as well as two clefts running N. and S., one on each side of the central mountain.

About 10 miles to the east of Agrippa is an isolated mountain mass marked M. Abutting on the W. wall is a large enclosure marked P, traversed from N. to S. by a cleft.

Albategnius. A fine walled plain about 80 miles in diameter with a massive complex boundary containing peaks rising from 10,000 to 14,000 feet in height. The interior contains a number of craters of which A and B are the largest. There is also the remains of a large central peak. The most interesting objects on the floor are a number of shallow saucerlike depressions, which are only visible for a short time when near the terminator.

SECTION I



Bode. A crater nearly 11 miles in diameter with walls bright and conspicuous at full. These rise about 5,000 feet above the interior.

Boscovitch. An irregular incomplete ring plain with many evidences of having suffered from erosive forces—the floor, which is one of the darkest spots on the Moon, is crossed by a cleft, difficult to detect.

Flammarion. A ring plain 40 miles in diameter, whose original walls seem to have been more or less destroyed by the erosive action of lava, when the Sinus Medii was forming. There are about 20 craterlets in the interior, those shown being the largest. The interior is also crossed by a cleft which joins a larger one running across the N.E. boundary nearly as far as Lalande.

Godin. A fine well-formed crater with high terraced walls. There is a peak at the centre of the interior. To the E. is a large oblong enclosure marked P.

Herschel. A large well formed circular crater 28 miles in diameter. The interior slopes are very bright and much terraced. At the centre is a massive oblong mountain mass. Outside to the N. is a smaller crater A, the interior of which appears to have been partly filled with lava. To the W. of A is a deep broad valley said to be 80 miles long and 10 miles wide in places.

Hind. A distinct crater to the W. of Halley, 16 miles in diameter, with walls rising to a considerable height—a little to the N.W. is a crater C from the N.E. walls of which 2 deep valleys cut through the mountains and debouch on the floor of Hipparchus.

Hipparchus. A vast mountain-ringed enclosure of very irregular shape, more than 90 miles in diameter. The walls are broken in many places by passes and deep bay-like indentations. The interior contains a great variety of craters and ridges ; most of the former, excepting Horrocks, seem to show traces of the erosive action of lava when the surface was in a molten condition.

Horrocks. A fine bright ring plain 18 miles in diameter and situated on the Western side of the interior of Hipparchus. From Horrocks there runs a delicate cleft S.W. to the wall of Hipparchus. In the interior of Horrocks are some low mountain masses.

Hyginus. A small crater about 4 miles in diameter, only remarkable for its association with one of the most interesting valleys or clefts on the Moon's surface. This cleft is visible with a 2-inch telescope and can be detected under all angles of illumination. The cleft runs westward for many miles, but after passing M it becomes narrow and more difficult to trace. That portion which runs N.E. from Hyginus is also easily seen in a small telescope. In large instruments the valley is seen to have many craterlike enlargements along its course.

Lalande. A ring plain 15 miles in diameter standing in an isolated position on the Mare Nubium. Its irregular walls are of no great height, but the interior, which contains a low central mountain, falls to a depth of some 6,000 feet below the plain. It is surrounded by many elevations which appear to have been reduced by the action of erosive forces in the past. To the S.W. will be found a long valley which extends as far as the rampart of Alphonsus, a distance of more than 130 miles.

Mösting. A ring plain 15 miles in diameter with regular circular walls rising 1,600 feet above the plain, and between 6,000 and 7,000 feet above the interior. It contains a central mountain peak. To the N.W. is a large ruined ring plain M, of the original walls of which only a few isolated ridges now remain.

Murchison. A fine specimen of a ruined ring plain about 35 miles in diameter, where only the N.W. segment of the original wall is complete. A few mountain ridges show the remains of what was once a complete ring of considerable importance. At the Southern end of the Western ridge is a fine crater A.

Pallas. Lies to the E. of Murchison and seems to have suffered less from erosion than its neighbour. Pallas is 35 miles in diameter and contains a central mountain peak. To the S. are a number of curved ridges which have the appearance of being all that now remain of several, at one time, complete rings.

Ptolemaus. A great walled plain about 90 miles in diameter.

It is the most northerly of a chain of three great meridional ring plains, the other two being Alphonsus and Arzachel. Ptolemaus is one of the best observed areas on the Moon, and has occupied the attention of many selenographers in the past, with the result that we have a complete record of all

the details to be found on its surface—these consisting of craterlets, crater pits, and shallow bowl-like depressions, numbering more than 100 in all, whose positions have been determined with great accuracy. On the interior, there is a fine cleft running alongside the eastern boundary, and passing through the wall into a wide valley as shown on the map. Most of the details mentioned require a powerful telescope for their detection.

Réaumur. Another fine specimen of a partially ruined mountain ring, having a diameter of about 20 miles. On the interior is a cleft R which joins another running at right angles with it. These objects are visible only in a powerful telescope.

Rhaeticus. A considerable ring plain N. of Hipparchus with irregular broken walls, rising in one place to about 5,000 feet—the ramparts are broad and contain a number of craterlets and depressions—a low mountain ridge is found on the interior ; the floor is crossed by a fine distinct cleft, which cuts through the wall and extends as far as Réaumur.

S

SECTION II

Schroeter. A mountain-ringed plain whose original walls have been reduced and partially destroyed by erosive forces. It will be noticed that a section of the S. wall has entirely disappeared. Near the centre is a small well-defined crater.

Silberschlag. A bright distinct deep crater 9 miles in diameter abutting on the S. side of the Ariadaeus Cleft.

Sinus Medii. One of the smaller plains (so-called seas) near the centre of the Moon's disc, comprising an area of about 13,000 square miles.

Sommering. An ancient ring plain, about 17 miles in diameter, whose walls have suffered from erosion in a similar manner to those of Schroeter, which it somewhat resembles. The E. wall is low, but the fragment of the W. wall, which now remains, rises to about 4,000 feet.

Triesnecker. A ring plain 14 miles in diameter, interesting not only in itself but also because of its association with a very remarkable system of clefts, which are found outside its western rampart. Some of these clefts are fairly easy objects even in small telescopes, but many of them are very delicate and require considerable optical means for their detection. It is a curious fact that no clefts have been found on the E. side of Triesnecker.

Ukert. A crater 14 miles in diameter, with polygonal walls. The surrounding country is very mountainous. The most conspicuous object is a fine valley V running N.W. to S.E., nearly 80 miles in length and having a breadth of 6 miles.

SECTION II.

Alfraganus. A crater 12 miles in diameter, noted for the brightness of its steep walls and surrounding surface. It contains a small central peak. To the South is a large smooth open plain (P) and a similar formation, also marked P, between Alfraganus and Taylor.

Arago. A fine deep ring plain 18 miles in diameter, in an isolated position on the M. Tranquilitatis. To the West are some curved ridges, evidently all that remain of once complete rings. There are two dome-shaped hills, one outside the E. wall and the other to the N. From Arago and extending as far as Sosigenes is a long cleft.

Ariadaeus. A small crater which is situated at the end of the well-known Ariadaeus cleft or valley, one of the most interesting specimens of this class on the Moon, easily seen in a small telescope. It runs for about 140 miles. In full Moon, all trace of it is lost.

Capella. A large ring plain fully 30 miles in diameter. Its walls are far from circular—at its centre is a massive mountain mass connected to the N.W. and S.E. ramparts by a ridge.

Cayley. A bright crater 10 miles in diameter with regular walls.

Censorinus. A brilliant little crater with bright surroundings, one of the brightest spots on the Moon.

Delambre. A large deep ring 32 miles in diameter with massive terraced walls—at one place the crest of the rampart rises to the height of 14,000 feet above the floor—which contains a small peak and some other details.

De Morgan. A small crater 3 or 4 miles in diameter. To the S. is an open plain P from which a coarse valley runs towards Delambre for about 40 miles.

Descartes. An incomplete ring plain 30 miles in diameter, with broken and irregular ramparts, the whole formation being ill-defined.

Dionysius. A ring plain 13 miles in diameter notable for its great brightness. To the West are several clefts—one R.4 connects Dionysius to Ritter.

Dollond. A small bright crater about 6 miles in diameter.

Gaudibert. A considerable crater with low walls—the floor contains several parallel ridges.

Hypatia. An irregular walled plain fully 30 miles in diameter. It has on its S. wall a fine crater A.

Isidorus. This fine irregular shaped enclosure abuts on the E. side of Capella, which it resembles only in size. Its floor is darker in tone and more depressed. It contains a fine crater A.

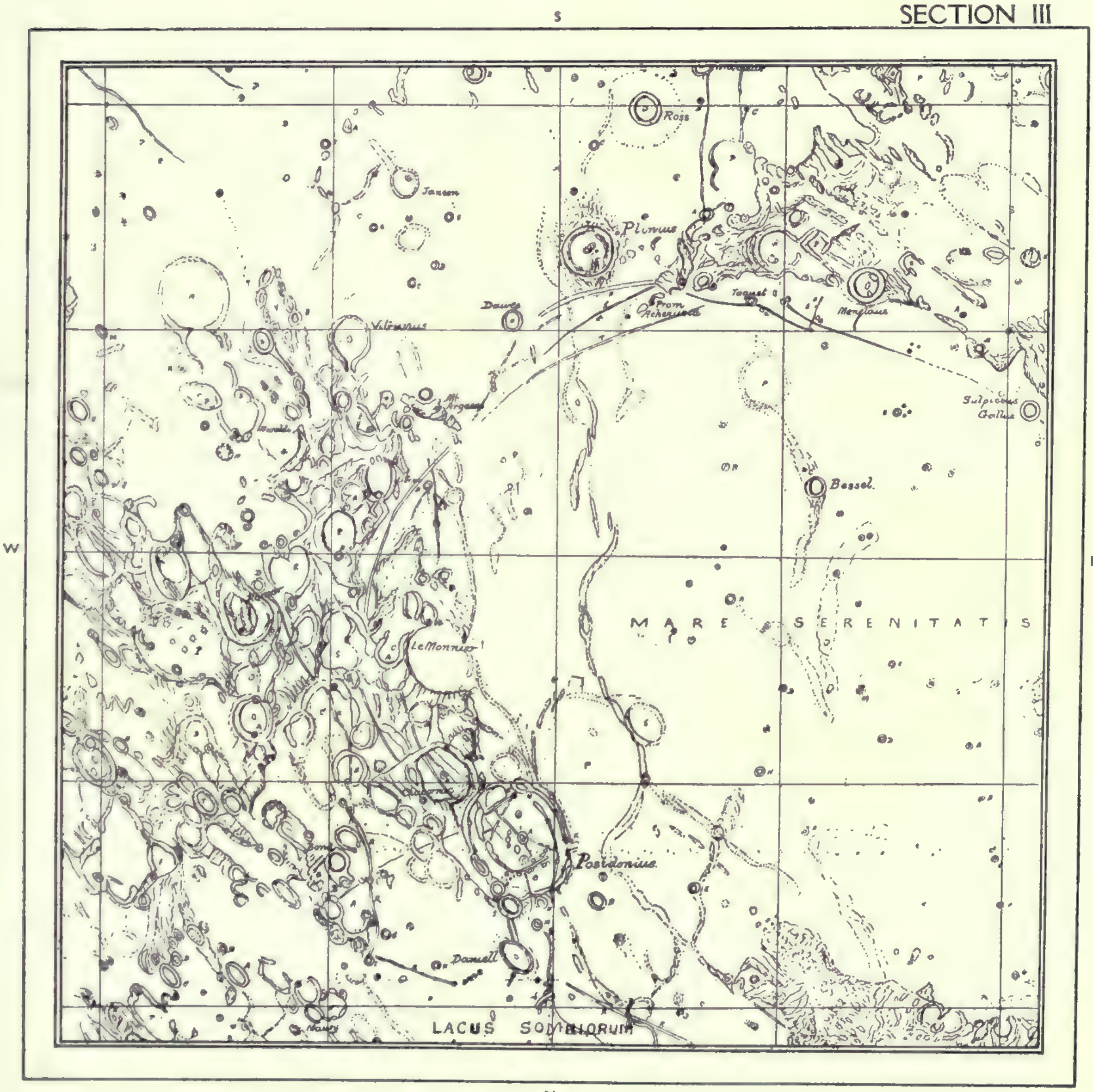
Julius Cæsar. A large incomplete walled plain of which the S.W. ramparts have almost entirely disappeared, thus giving it the appearance of a great bay on the shores of the M. Tranquilitatis—the interior is very dark, especially to the N. It is quite smooth except for a few craterlets. There is a wide valley outside the W. wall consisting of several large confluent craters.

Kant. A deep ring plain 21 miles in diameter with very bright walls and visible under all angles of illumination. The walls are said to be double. It has a large central mountain peak. On the plain to the W. is a massive mountain A rising to the height of 14,000 feet.

Maclear. A small irregular shaped crater. The floor is only slightly depressed below the plain, and gives the impression of having been partially filled up with lava—it contains a feeble central hill—running N. is a delicate cleft.

Mädler. A ring plain on the Mare Nectaris about 20 miles in diameter with walls rising some 6,000 feet above the interior, which contains a central peak connected to the N. rampart by a ridge. The

SECTION III



Eastern half of the floor is much darker than the Western. From the West wall runs a bright curved streak for about 50 miles, terminating at the bright crater A.

Manners. A small distinct crater 9 miles in diameter with a small peak at its centre.

Maskelyne. A fine distinct ring plain on the M. Tranquilitatis, about 18 miles in diameter. The walls, which are not circular, are terraced on the inner sides. It contains a central mountain of moderate size.

Mare Tranquilitatis. One of the darkest and largest of the great grey lunar areas termed " maria " by the ancient astronomers. Its surface, as will be noticed from the maps, is covered with innumerable ridges, hills, mounds, craters and craterlets, and is scarified by many clefts and valleys.

Ritter. A companion ring to Sabine, having walls rising about 4,000 feet above the depressed interior. To the S. is a small crater to which Neison has attached the name of Schmidt. Ritter is the centre of a complex system of clefts as shown on the map. Some of these are within the reach of small telescopes, but others require very powerful instruments to detect them.

Ross. A fairly distinct ring plain about 18 miles in diameter. It contains a small central peak.

Sabine. Very similar in size and appearance to Ritter, and is a good illustration of the fact that craters on the Moon are often found in pairs of equal size. From the S. side run two parallel clefts along the margin of the mare.

Sosigenes. A small ring plain with regular circular walls about 14 miles in diameter. Between Sosigenes and Maclear are the remains of a once complete ring of considerable size. It has at its centre a slight mountain peak.

Taylor. A deep elliptical ring plain 25 miles in length. The interior contains a central peak and some ridges, also a craterlike depression.

Theon Jr., and Theon Snr. Two bright craters almost identical in size and appearance with level interiors, each about 11 miles in diameter.

Theophilus. A magnificent mountain-ringed plain—one of the finest objects of its class on the Moon's surface, and presenting a splendid spectacle when seen under the rays of the rising or setting sun ; it is about 64 miles in diameter, its massive ramparts rising in places from 14,000 to 18,000 feet above its interior. The inner walls are very rugged and terraced. On the interior is a massive central mountain split up into several high peaks. From the outer walls to the N. run a number of radial ridges, which can be traced as far as Torricelli, and on the Western side some distance on the surface of the M. Nectaris.

Torricelli. A curious small ring plain having a smaller companion in contact with its E. side, the common wall separating them being broken down at the point of contact. Torricelli stands on the floor of a large ancient ring P, and this is traversed N. to S. by a delicate cleft or valley.

Whewell. A small bright crater east of Cayley and about 7 miles in diameter. On the environs of Whewell the surface is pitted by a great many small craters which require considerable optical power to reveal them.

SECTION III.

Bessel. The largest and brightest crater on the surface of the Mare Serenitatis, about 10 miles in diameter, with a continuous ring rising about 4,000 feet above the interior. Bessel stands on a long curved ridge.

Bond. A distinct crater about 12 miles in diameter. On its Eastern side is a long cleft or valley running N. and S. Its length is about 170 miles. It terminates near the Eastern side of Römer.

Chacornac. An irregular polygonal ring plain about 30 miles in diameter. At its centre is a craterlet, and the floor is crossed by 2 ridges and 2 clefts. The latter seem to connect with 2 others running in the direction of Le Monnier.

Daniell. A conspicuous ring plain 18 miles in diameter—through foreshortening it appears elliptical in shape. It is connected with Posidonius by some ridges and a cleft.

Dawes. A small ring plain near Plinius, standing on a large bright area, and containing a small central mountain.

Jansen. An obscure ring plain, whose low walls have apparently been reduced by erosion and the interior partly filled up with lava when the surrounding sea was in a liquid condition.

Le Monnier. An incomplete ring plain about 33 miles in diameter which now appears as a great bay in the margin of the M. Serenitatis—where its Eastern ramparts once stood, there are now only low ridges.

Littrow. A small ring plain in the mountainous country bordering the M. Serenitatis. Its Southern wall is broken by several wide passes. Outside its E. wall is a long curved cleft not easily seen.

Maraldi. A large ring plain with a smooth dark interior, has apparently been partially filled up by material flowing in from an adjacent mare when the latter was in a liquid state.

Maury. A small crater hardly of sufficient importance to be specially named.

Menelaus. A fine distinct bright crater about 20 miles in diameter, standing on the S. margin of the M. Serenitatis. Its walls are bright, massive, broad and steep and rise to about 6,000 feet above

SECTION IV

the interior, which contains a central peak and other elevations. To the S.W. is a curious square enclosure marked P. A bright streak extends from Menelaus across the mare and beyond Bessel.

Plinius. A splendid example of a large mountain ring plain with high massive walls, about 32 miles in diameter. The interior, which is darker than the surrounding plain, contains a complex central mountain, which sometimes appears as two craters in contact. To the N. and on the margin of the mare are at least three parallel clefts—the nearer one not being difficult to see.

Posidonius. A large and interesting walled plain on the W. margin of the M. Serenitatis 61 miles in diameter. The ramparts, however, do not rise more than 6,000 feet at any point. Those on the seaward side seem to have better withstood the undermining and erosive action of the once liquid surface of the mare, but there is a distinct break at one point, through which probably this liquid material gained entrance to the interior. On the interior are a number of clefts, craterlets and isolated hills.

Römer. A curiously irregular shaped mountain ring standing in the midst of the Taurus Highlands. Its largest diameter is about 35 miles. The walls are broad and terraced on the inner sides, and the floor contains many irregularities.

Mare Serenitatis. One of the most prominent of the lunar grey plains, with fairly well-defined borders, which are in part formed by the Caucasus, Apennines, Haemus, and Taurus mountain ranges—its coast line is about 1,850 miles in length, and it occupies an area of nearly 125,000 square miles.

Sulpicius Gallus. A distinct crater on the margin of the mare, 8 miles in diameter.

Taquet. 5 miles in diameter with bright walls and standing on a bright area; some clefts are associated with this object, as shown on the map.

Vitruvius. A conspicuous crater ring 20 miles in diameter with bright walls and a dark interior, on which there is a feeble central mountain.

SECTION IV.

Apennine Mountains. The most important range on the Moon. It forms a portion of the S.W. boundary of the Mare Imbrium, presenting a very fine spectacle under a rising or setting sun. In this range are four high peaks: Mt. Wolf, 12,000 feet; Mt. Huygens, 18,000 to 20,000 feet; Mt. Bradley nearly 16,000 feet, Mt. Hadley, 15,000 feet. The mountains on the seaward side fall abruptly to the plain, and present the appearance of a long line of cliffs when seen at sunset. This line is broken in many places by wide valleys which go back into the mountainous hinterland.

Aratus. A small bright crater 8 miles in diameter, situated in the Apennine Highlands.

Archimedes. A fine ring plain 50 miles in diameter with broad low massive walls only rising about 4,000 feet above the smooth interior, which is intersected E. to W. by a system of bright streaks, and on which are a number of small craters, not easily seen. Between Archimedes and the Apennines are a number of clefts, some coarse, others very delicate objects.

Aristillus. A fine large ring plain 35 miles in diameter with complex walls rising to 8,000 feet on the E. and 11,000 feet on the W. above the interior, on which stands a massive central mountain; from the outer walls radiate ridges apparently of lava, which extend for long distances.

Autolycus. A companion to Aristillus, though smaller in size, being 25 miles in diameter. Its circular walls rise to about 9,000 feet above the interior; a chain of ruined crater rings runs tangentially across the floor.

Beer and Beer A. A pair of small well-defined circular craters. From Beer runs a cleft or chain of craterlets as shown, but not easily seen.

Conon. A distinct deep crater 15 miles in diameter, situated in the heart of the Apennine mountains. It possesses a central peak.

Caucasus Mountains. A range of massive mountains forming the N.E. boundary of the M. Serenitatis. It contains peaks varying in height from 6,000 to 12,000 feet, whilst one mountain near Calippus is said to reach 21,000 feet.

Eratosthenes. A fine ring plain 38 miles in diameter at the Eastern terminus of the Apennine

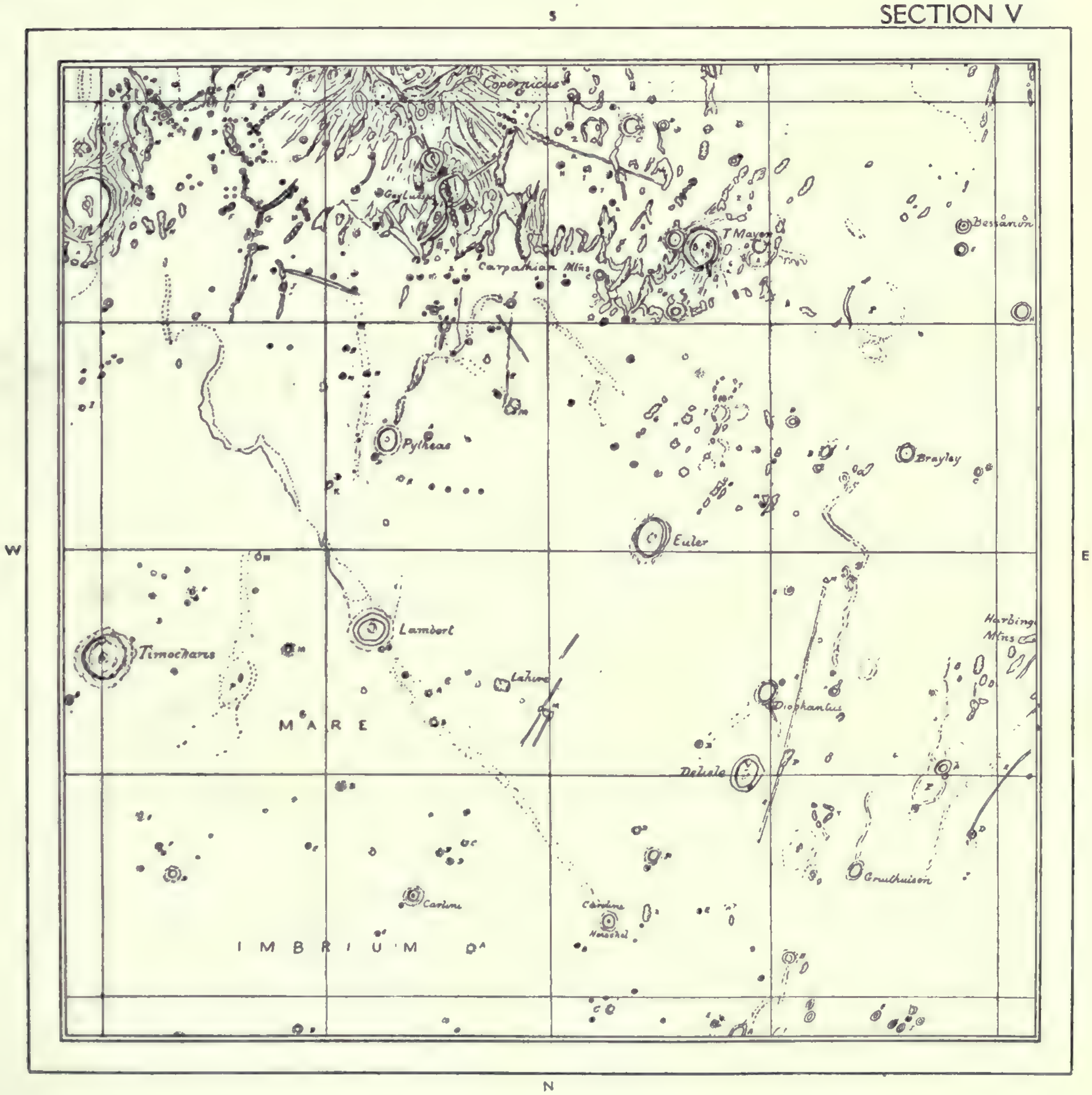
range. The rampart is circular, but sometimes has the appearance of a number of linear or curved segments. One peak on the wall rises 16,000 feet above the interior. On the W. the wall rises about 10,000 feet. The massive complex central mountain sometimes presents the appearance of a crater ring.

Haemus Mountains. Form the S.E. border of the M. Serenitatis with peaks rising from 4,000 to 8,000 feet above the plain.

Linné. A small crater standing on the edge of a small ruined ring plain. One of the objects on the Moon where a great change has been thought to have taken place in modern times. Not an easy object to observe.

Manilius. A fine bright ring plain 25 miles in diameter and easily seen under all angles of illumination. The wall, linear in parts, rises 7,000 feet above the interior, which contains a complex mountain mass.

SECTION V



Marco Polo. A small circular crater in the Apennine Highlands standing near a remarkably wide and long valley.

SECTION V.

Bessarion. A small bright ring plain with a similar object to the S (E.). Both stand on bright areas.

Brayley. A conspicuous bright ring plain 9 miles in diameter.

Carpathian Mountains. A series of mountain masses extending over 125 miles in length. Here and there peaks rise from 5,000 to 7,000 feet.

Carlini. A small distinct crater with walls rising about 2,000 feet above the interior, which contains a central peak.

Delisle. A ring plain 16 miles in diameter, with irregular walls rising 6,000 feet above the interior —it contains a low central mountain. To the E. on the plain is a long straight ridge P.

Diophantus. A small ring plain with regular walls rising about 3,000 feet above the interior, which is level and devoid of detail. Outside to the E. is a long valley R, terminating at a mountain M.

Euler. A ring plain somewhat elliptical in form—19 miles in diameter—with a floor depressed 6,000 feet below the crest. It has a considerable bright central mountain. To the S. is a group of isolated hills. Euler stands at the centre of a number of radiating bright rays.

Gay Lussac. A ring plain of more than ordinary interest 15 miles in diameter. On the interior are a cleft and a chain of craters running across the floor and continuing beyond the N. wall for some distance.

Gruithuisen. A bright little ring 10 miles in diameter; between it and Delisle is a curious group of mountain ridges T and an ancient ring just below.

Caroline Herschel. A bright ring plain about 3,000 feet deep and containing a central peak. From Car. Herschel extends a very long ridge as far as Lambert.

Mare Imbrium. This is the greatest of the lunar plains or seas, having a length of 750 miles and a breadth of 670 miles. The area being about 340,000 square miles. It is very variable in brightness and contains a great number of light streaks and spots.

La Hire. A bright mountain mass 5,000 feet in height, having a base length of 10 miles. To the N.E. is another mass M, having 2 clefts associated with it.

Lambert. A fine isolated ring plain on the M. Imbrium, nearly 19 miles in diameter, with well-defined circular walls of irregular height. The central mountain is sometimes seen to be of crater-like form. Lambert stands on a long serpentine ridge. To the E. is a mountain M, which shows as a very bright spot about full Moon.

T. Mayer. A considerable ring plain 22 miles in diameter. Its W. wall is said to rise 9,000 feet above the interior. On the interior are several objects. In contact with the W. slope is a fine distinct bright crater A.

Pytheas. A ring plain 12 miles in diameter with rhomboidal walls. The walls and interior are bright and at full Moon the whole is seen as a bright round spot. From the S.E. wall runs a strong mountain arm for 25 miles.

Timocharis. A fine ring plain 23 miles in diameter with walls rising about 7,000 feet above the interior. The central mountain has a craterlet on its summit.

SECTION VI.

Bonpland. One of a group of three obscure mountain-walled plains, the others being Parry and Fra Mauro. It is 30 miles in diameter. On the interior are three clefts and a few irregularities. On the plain to the E. is a group of isolated mountain masses E, the highest of which rises about 2,500 feet.

Copernicus. The grandest of all the large crater rings on the Moon—56 miles in diameter—presenting a superb spectacle under morning or evening illumination. The walls which rise to about 12,000 feet above the interior are at the crest thin and sharp. The inner slopes are much terraced.

The floor, 40 miles in diameter, is more circular than the crest and contains a multiple central peak. Radiating from the walls are many lava ridges. Copernicus stands on a bright area, from which bright rays spread in all directions.

Encke. A ring plain 20 miles in diameter with polygonal walls less than 2,000 feet in height. It has a central ridge running N. and S.

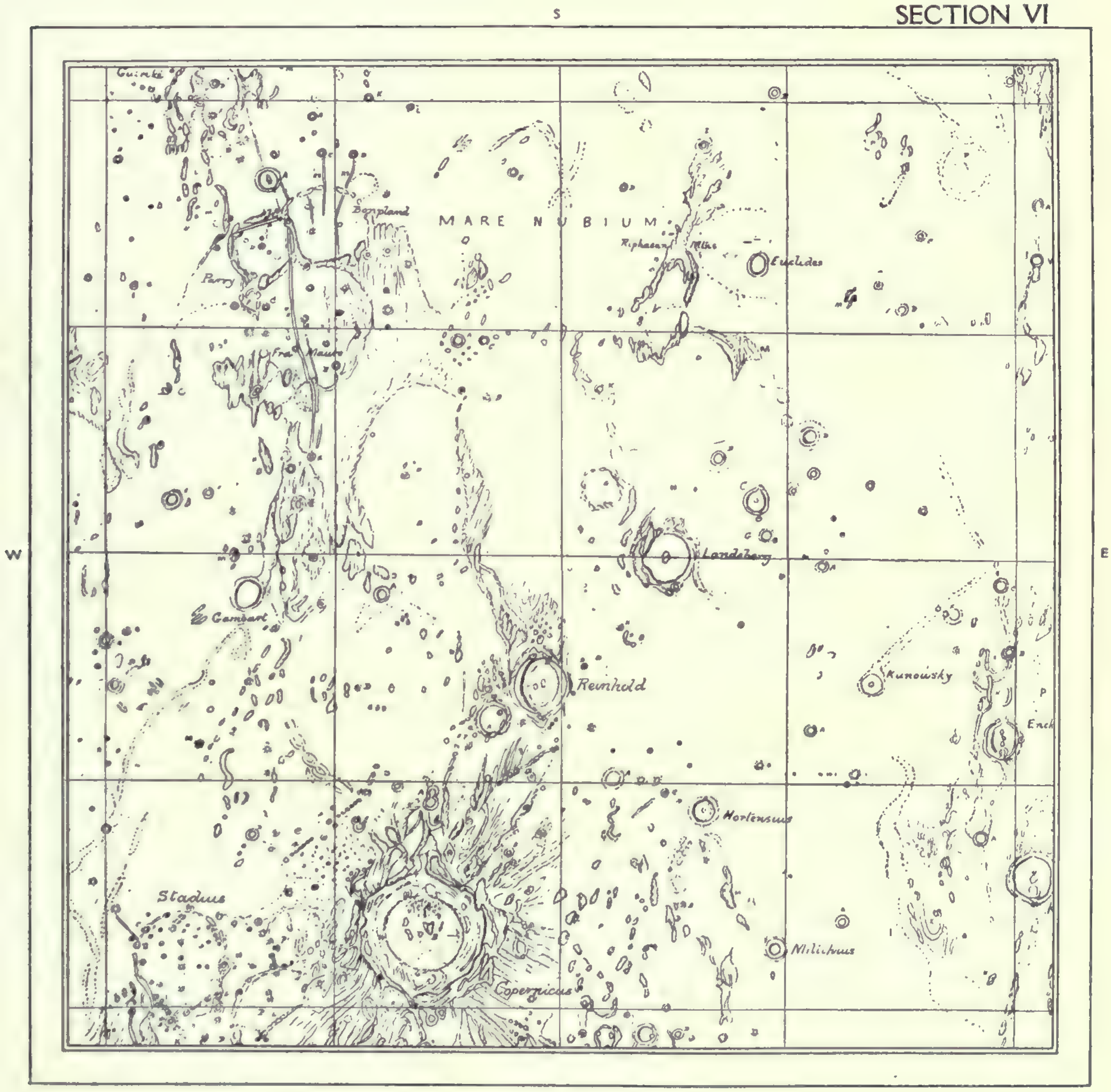
Euclides. A very bright crater 7 miles in diameter and standing on a bright area.

Fra Mauro. A large ruined ring plain about 50 miles in diameter. The original walls have been greatly reduced by erosive action. The interior contains a number of parallel ridges, some craterlets and a large cleft or valley which traverses it from N. to S.

Gambart. A small ring plain 16 miles in diameter with a dark smooth interior.

Gueriké. A partially ruined ring plain with much reduced and fragmentary walls. A wide valley traverses the interior N. to S. It also contains some craterlets, a hill and small cleft.

SECTION VI



Hortensius. A fine deep bright ring about 10 miles in diameter. The interior contains a central peak, and some bright rays are associated with this crater. On the plain to the N.W. is an obscure ring plain A.

Kunowsky. A small ring plain 12 miles in diameter with low irregular walls. A bright ray runs from the S.E. wall for about 60 miles.

Landsberg. A fine ring plain 28 miles in diameter, with a central peak. The massive terraced walls are high, rising at one place to 10,000 feet. To the S.W. is a large obscure ring G.

Milichius. A distinct bright crater 10 miles in diameter. To the S.W. is a mountain mass M, 3,000 feet in height.

Parry. A ring plain 25 miles in diameter, with walls broken at places, rising at one peak to 4,900 feet. It has on the interior a distinct crater and a cleft which runs E. and W. under the S. wall, and one under the W. and E. walls. The latter is a continuation of the one which traverses Fra Mauro.

Riphaean Mountains. 120 miles in length.

Reinhold. A fine ring plain 30 miles in diameter, with steep and lofty walls rising at one place on the W. to 9,000 feet above the floor, which contains a large but low central peak. There is a small ring plain A on the N.W. side. Many small mountains are scattered on the plain to the S.

Stadius. A ruined ring plain W. of Copernicus, of which the original walls have entirely disappeared, or are represented by curved banks. It contains a large number of craterlets, some of which form chains.

SECTION VII.

Agatharchides. A large irregular walled plain, about 30 miles N. to S. On the interior are several mountain ridges.

Bullialdus. A noble object 38 miles in diameter, of the same type as Copernicus. Its rugged and much-terraced ramparts rise to fully 8,000 feet above the interior. On all sides there are ridges radiating from the walls, which can be traced for many miles. There is a complex central peak of no great height.

Campanus. A large regular ring plain of about 30 miles in diameter. Its smooth floor contains a few irregularities not easily seen.

Capuanus. A large irregular ring plain some 35 miles in diameter, the rampart rises to about 8,000 feet above the interior. The smooth floor is only disturbed by two or three minor elevations.

Cichus. A bold deep ring plain more than 20 miles in diameter, with broad massive walls rising 8,000 feet above the interior. On the crest of the E. wall is a fine crater G.

Clausius. A small distinct ring plain near Drebbel.

Doppelmayer. A fine specimen of a large ruined ring plain on the margin of the M. Humorum, about 40 miles in diameter. There is a large central hill—the wall on the seaward side has practically disappeared.

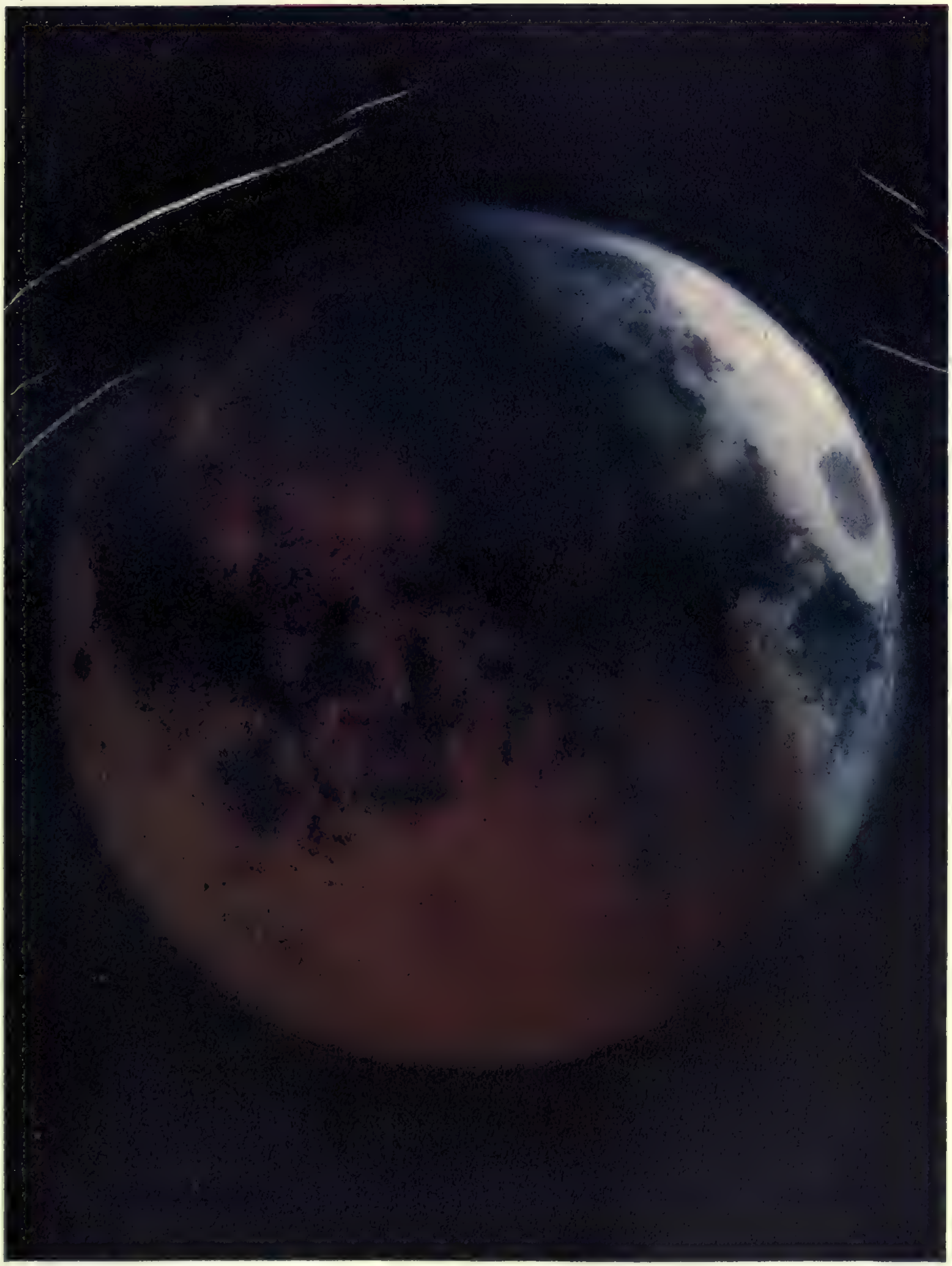
Gassendi. 55 miles in diameter, is one of the most interesting ring plains on the Moon's surface and has been extensively observed. The walls are irregular in height, and polygonal—reduced to mere banks on the S. On the interior is a complex central mountain, many craterlets and an interesting system of clefts; some are easy but many quite difficult to see.

Herigonius. A small ring plain 7 miles in diameter.

Hesiodus. A ring plain abutting on the E. side of Pitatus, about 20 miles in diameter. On the interior is a distinct central crater. From the E. side extends a long wide valley as far as Capuanus, one of the finest of this type on the Moon.

Hippalus. An interesting ring plain on the W. side of the M. Humorum, about 38 miles in diameter. The S.E. rampart has been entirely destroyed. The interior is traversed N. to S. by a fine cleft, which is interrupted by several craters through which it passes.

Kies. An ancient ring plain about 28 miles in diameter, whose walls have been reduced very much by erosion. The smooth floor contains several minute craterlets.



AN ECLIPSE OF THE MOON.

The Moon is here shown entering the Earth's shadow. Note the bluish band near the edge of the latter, which appears by contrast darker than the more central portions. The coppery hue is due to the red rays of the sunlight which have been refracted into the geometrical shadow by the Earth's atmosphere the rays of shorter wave length having been absorbed. An observer on the Moon at the time of total eclipse would see the Earth surrounded by a ring of red light analogous to the colour effects commonly observed at sunrise and sunset, but more marked owing to the longer path traversed by the rays through the Earth's atmosphere. In the illustration the craters Tycho and Aristarchus and other surface details can be plainly seen in the shadowed part of the Moon by this refracted light.

Lee. Another ruined ring plain near Doppelmayer.

Lubiniesky. A large ring plain, which, like Kies, has suffered much from erosive forces.

Mare Humorum. One of the smaller seas, about 260 miles N. to S. and 280 E. to W., with an area of about 50,000 square miles. There are a number of curved ridges near the borders, and many craterlets scattered over its surface. Near the W. side is a huge mountain mass M.

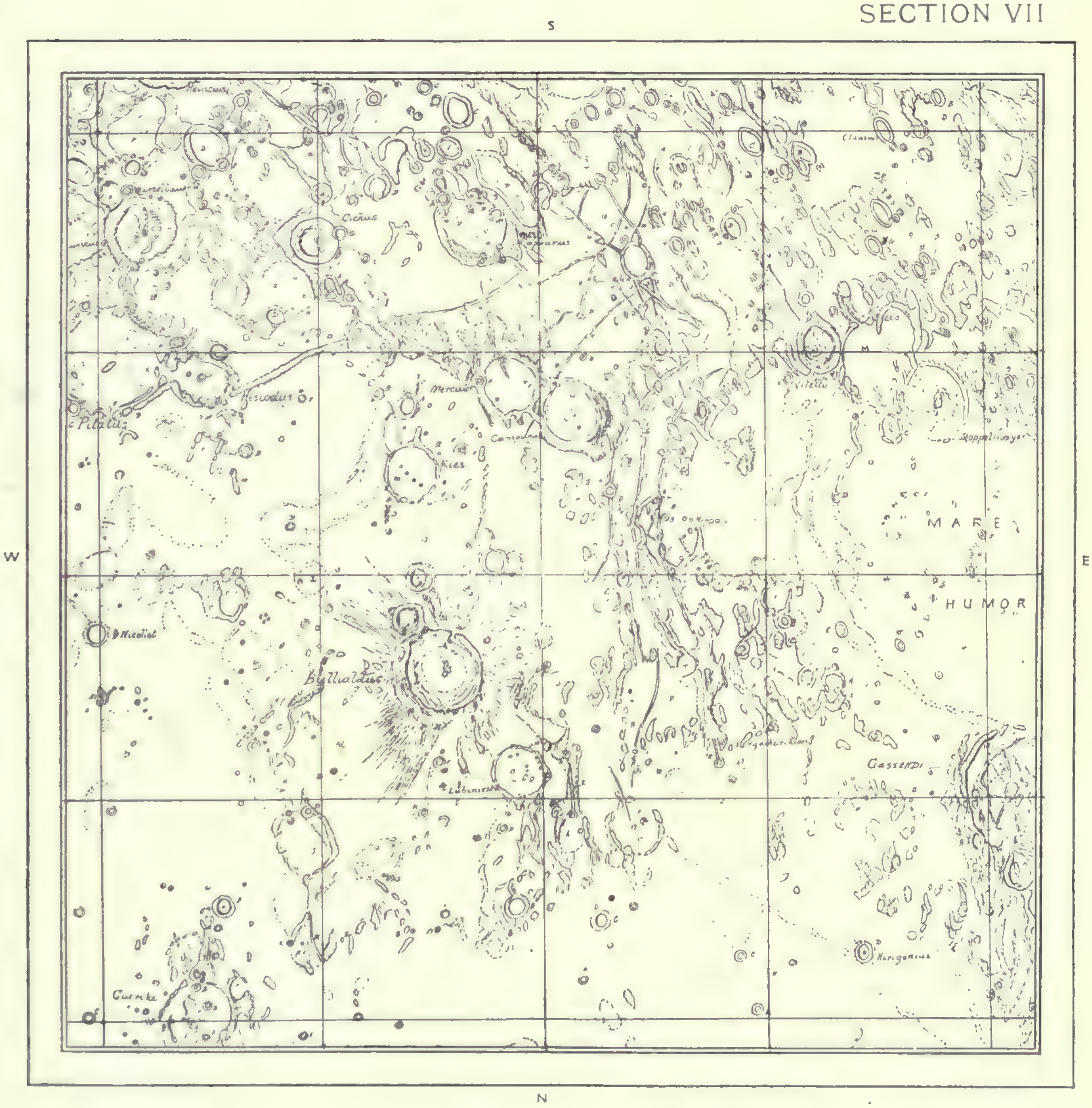
Mercator. A large ring plain similar in many respects to its companion, Campanus.

Nicollet. A small ring plain 11 miles in diameter.

Pitatus. A large and most interesting walled plain, with a level floor 45 miles in diameter. There is a low central mountain and several clefts near the foot of the wall in various places. There is a wide pass in the E. wall running into Hesiodus.

Ramsden. A small crater ring about 12 miles in diameter, standing at the centre of a fine system of clefts.

SECTION VII



Vitello. A fine ring plain about 30 miles in diameter. Possesses a double ring and a small central mountain.

Wurzelbauer. A large irregular walled plain about 45 miles in diameter, with ramparts very broken and complex. It has a number of ridges and other objects on its interior.

SECTION VIII.

Abenezra. 26 miles in diameter, with walls rising to 5,000 feet above the plain and 14,500 feet above the interior, thus being one of the deepest craters on the Moon. Abenezra has encroached on an older formation (A). The whole of the surroundings are crowded with all kinds of crater formations.

Airy. A small ring plain with lofty broad walls and a central peak.

Apianus. A fine ring plain 38 miles in diameter, with fairly regular walls, which rise about 9,000 feet above the smooth interior, broken only by 2 or 3 small craterlets.

Aliacensis. 53 miles in diameter. The shape of the walls departs considerably from a circle. On the inner side of the W. wall, there is evidence of a great landslip. Generally the walls are massive and much terraced, and rise in places from 12,000 to 16,000 feet above the floor.

Alpetragius. A fine massive ring plain 26 miles in diameter, with complete circular walls rising on the W. to 12,000 feet above the interior, which contains a large central mountain. A little to the E. is B, a bright crater standing on a bright area.

Alphonsus. A great walled plain about 65 miles in diameter, with massive irregular ramparts in places 15 miles wide at the base, rising 5,000 to 9,000 feet. The interior contains a number of interesting objects, including several dark spots and clefts associated with them.

Argelander. A small ring plain 20 miles in diameter, with terraced walls and a central peak.

Arzachel. A fine massive walled plain more than 60 miles in diameter, with regular and much terraced ramparts rising 10,000 to 13,000 feet above the interior, which contains a number of hills and craters, and a fine cleft running at the foot of the W. wall.

Ball. A deep ring plain 25 miles in diameter, with walls rising to 5,000 feet in height. There is a large central mountain on the floor.

Birt. A small ring plain with bright circular walls broken by a small crater on the Western crest. A fine cleft runs N. and S. just outside the E. wall, the Southern half of which is difficult to see.

Blanchinus. A large walled enclosure about 53 miles in diameter. The interior has two levels and is traversed N. and S. by a number of parallel ridges.

Davy. An irregular deep ring plain 20 miles in diameter. Its wall on the S.W. is broken by a large crater A. To the N.W. is a curved cleft or valley, whose course is interrupted by four craterlets. On the interior of Davy there is a delicate cleft and the remains of a central peak.

Delaunay. A massive ring plain divided into two parts by a large ridge.

Donati. A small ring plain 20 miles in diameter with irregular walls.

Faye. Similar to Donati.

Fernelius. A walled plain 30 miles in diameter. The floor is free from detail except a few craterlets.

Gauricus. A fine walled plain 38 miles in diameter with walls rising about 9,000 feet above the interior. The chief object on the floor is the incomplete ring F.

Gemma Frisius. An immense mountain walled enclosure with irregular ramparts, rising at one peak to 14,000 feet. There are a number of hills and craters on the interior.

Hell. Named after the Astronomer of that name. A conspicuous ring plain 20 miles in diameter with high and terraced walls. The floor contains a few hills. There are a number of curved parallel valleys outside the W. wall.

Lassell. A small ring plain with low walls 14 miles in diameter. To the E. is a mountain ridge C, and farther on D, a bright craterlet on a bright area.

Lacaille. A large ring plain 40 miles in diameter with walls rising to 9,000 feet. The smooth floor contains a number of craterlets.

Lexell. A large ruined ring plain with walls very much reduced by erosion, especially on the N. side. There is a group of large craters at the centre.

Nonius. An irregular shaped walled plain of no particular interest.

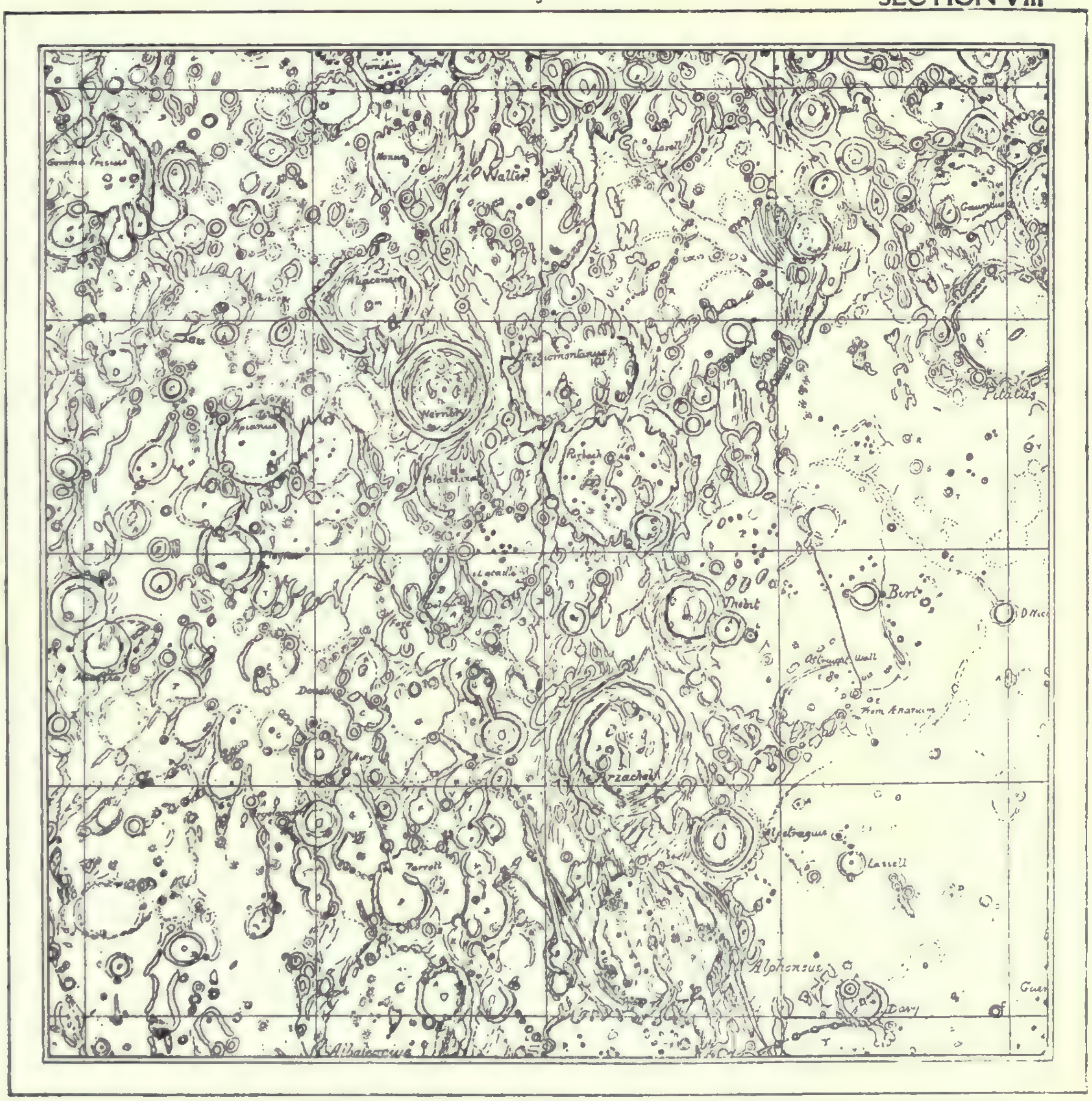
Playfair. A fine distinct ring plain 28 miles in diameter, with a smooth floor containing two craterlets.

Parrott. A large, irregular, ill-defined enclosure about 40 miles in diameter. It is almost separated into two parts by a curved mountain ridge.

Poisson. An elliptical ring plain 50 miles by 30 miles.

Purbach. An immense walled plain fully 70 miles in diameter, with irregular ramparts rising about 8,000 feet. The interior contains many small and large craters, ridges and hills.

SECTION VIII



Regiomontanus. A large formation of irregular shape; measured from E. to W. the diameter is nearly 80 miles. On the interior are a number of horseshoe-shaped ridges, evidently the remains of once complete rings.

The Straight Wall. A remarkable linear formation more than 60 miles in length, once mistaken for an artificial object. In reality, it is a fault in the surface. An idealistic drawing of this is to be found on page 293.

Thebit. A fine distinct ring plain 30 miles in diameter. The normal circular wall has been distorted by the intrusion of a smaller ring plain A, which latter in its turn has a small crater on its eastern flank. The interior of Thebit is very rough. To the N.E. is a large circular enclosure P.

Walter. A vast polygonal walled enclosure about 85 miles in diameter, its massive complex ramparts containing peaks up to 10,000 feet in height. The interior contains many interesting features, and the whole formation when seen under a low angle of illumination presents a very fine spectacle.

Werner. A remarkable circular ring plain 45 miles in diameter with high walls rising about 13,000 feet above the interior. On the E. they are said to reach an elevation of 16,000 feet. The interior walls are terraced and the floor contains a number of interesting formations.

SECTION IX.

Abulfeda. A fine ring plain 39 miles in diameter, with steep lofty terraced walls on the E. rising to 10,000 feet. A remarkable crater valley runs tangentially from the S.E. wall as far as Almamon.

Almamon. 28 miles in diameter, with moderately high walls and a floor containing no notable detail.

Altai Mountains. Run for a distance of about 315 miles. The crest varies in height from 4,000 to 6,000 feet. It is said there are peaks however rising to 11,000 and 13,000 feet. The Western slope of the range is precipitous.

Azophi. A companion ring to Abenezra and about the same size.

Beaumont. A ring plain 30 miles in diameter, with rather low walls which show signs of erosion in several places. The interior contains many objects of interest including a crater chain. A long mountain ridge runs N. to Theophilus.

Busching. Has a broken wall about 4,000 feet high, and on the interior little or no details of importance.

Catherina. A large and interesting walled plain. The walls are broken, with many peaks, craters and depressions, and it gives the impression generally with Cyrillus of belonging to the oldest order of formations on the Moon.

Cyrillus. Resembles Catherina in many ways, but is smaller. Probably both were formed at the same epoch.

Descartes. An incomplete ring plain about 30 miles in diameter, with irregular, broken and generally ill-defined walls. On the floor is a fine distinct crater A.

Fermat. 25 miles in diameter with a floor depressed about 6,000 feet below the crest of the rampart. To the N. are two rings B and C, whose interiors have been filled with lava almost to the top of their walls.

Fracastorius. A ruined mountain-ringed plain whose Northern walls have been reduced by erosion almost to the level of the plain. The interior contains much fine detail, which has been thoroughly observed and mapped by several astronomers. It is about 60 miles in width.

Geber. A well-defined circular walled plain, with bright terraced walls rising from 4,000 to 6,000 feet above the interior. The floor is free from notable detail.

Lindenau. A large elliptical walled plain with regular walls. On the interior is a complex central mountain.

Neander. A ring plain, with massive regular and much terraced walls 34 miles in diameter. The rampart rises in places to 8,000 feet above the interior, which contains a large central mountain and other objects.

Pons. A large ear-shaped formation.

Piccolomini. A noble ring plain 55 miles in diameter, with massive walls rising from 9,000 to 14,000 feet above the interior. The floor is free from detail except a large complex central mountain.

Polybius. A ring plain 21 miles in diameter, with low wall and a floor smooth and free from detail.

Rabbi Levi. A fine large mountain-walled ring. The walls are irregular and broken by craters and depressions. There is a series of parallel passes or valleys in the S. wall. The interior contains some fine crater rings.

Rheita. A fine ring plain, elliptical through foreshortening, about 40 miles in diameter, with massive walls, carrying peaks rising to 14,000 feet above the interior, which contains a central peak.

Riccius. A large irregular enclosure about 40 miles in diameter, with a broad terraced wall on the E. and on the floor some crater rings with low walls.

Rosse. A fine deep bright crater 8 miles in diameter. One of the brightest spots on the Moon. A fine bright ray runs to N.W. past Bohnenberger.

SECTION IX

Sacrobosco. A large irregular walled plain about 55 miles in diameter. On the E. the rampart rises to 14,000 feet ; on the interior are two large crater rings.

Stiborius. A distinct ring plain about 25 miles in diameter, with irregular walls. There is a peak at the centre of the floor.

Zagut. A large irregularly-shaped mountain-walled plain, 50 miles in width. At one place on the S.W. the rampart rises to 9,500 feet. A large ring plain E. has intruded on the Western side of the floor.

SECTION X.

The principal objects of importance in this section are the great mountain-walled plains near the limb and lying in a meridional direction, Vendelinus, Petavius and Furnerius.

Adams. A considerable ring plain with broken walls, containing some lofty peaks.

Ansgarius. A well-defined ring plain about 50 miles in diameter, close to the limb, with apparently quite smooth floor.

Bhaim. A fine walled plain, with regular walls. It has a central peak.

Bellot. A distinct bright crater, 11 miles in diameter, of great depth.

Biot. A fine bright regular crater, about 10 miles in diameter, standing in an isolated position on the *mare.*

Bohnenberger. An interesting ring plain about 22 miles in diameter. The wall is broken at the N. by a pass, and the interior has a curved central ridge.

Borda. A ring plain about 25 miles in diameter, with high regular walls ; has a central peak and a large crater between it and the W. wall.

Colombo. A large mountain-ringed plain, about 47 miles in diameter. Its walls depart from the circular form owing to the intrusion of a large crater A, 25 miles in diameter. At the centre of Colombo is a complex mountain of not less than four peaks. There are some wide valleys also on the floor on the Western side.

Crozier. A small ring plain of little importance.

Cook. A ring plain, about 27 miles in diameter, with a dark interior containing a distinct craterlet at the foot of the S.W. wall.

Hase. A large ring plain abutting on the S.W. side of Petavius, with steep rugged walls rising about 7,500 feet above the interior, which contains several craterlets.

W. Humboldt. A magnificent mountain-walled plain, one of the finest of its class, but owing to its proximity to the limb it is rarely seen under good conditions. It is elliptical through foreshortening, being in reality a circle 130 miles in diameter. One of the peaks on the E. wall rises some 16,000 feet. The interior walls show evidences of landslips.

Legendre. A large irregular mountain-walled plain, about 46 miles in diameter. Down the centre runs a mountain ridge, and there are some craterlets on either side of it.

Maclure. A small ring plain about 15 miles in diameter, with a small central elevation.

Magelhaens. A ring plain about 24 miles in diameter, with a smooth interior dark in tone.

Reichenbach. About 40 miles in diameter, without notable detail on the interior.

Palitzsch. A long valley-like enclosure outside the W. wall of Petavius, about 100 miles long and 14 wide.

Petavius. One of the finest mountain-walled plains on the Moon. Its massive high walls are in parts double. On the E. the crest rises to 10,000 feet and on the W. to 6,000 above the interior. The length from crest to crest is over 100 miles. The interior contains many objects of interest, including a complex central mountain 5,000 feet in height, a long wide valley about 25 miles long and 2 miles wide, running from the centre to the S.E. wall. There are also several other clefts not easily seen.

Phillips. A large elliptical ring plain on the E. side of W. Humboldt.

Santbech. A fine mountain-ringed plain about 42 miles in diameter, with lofty ramparts rising on the W. to about 10,000 feet, and on the E. to 15,000 feet above the interior, which contains a prominent central peak.

Snellius. A mountain-ringed plain with walls rising about 6,000 feet above the interior. There is a central peak, and from this runs a wide valley to the S., passing through a gorge in the wall.

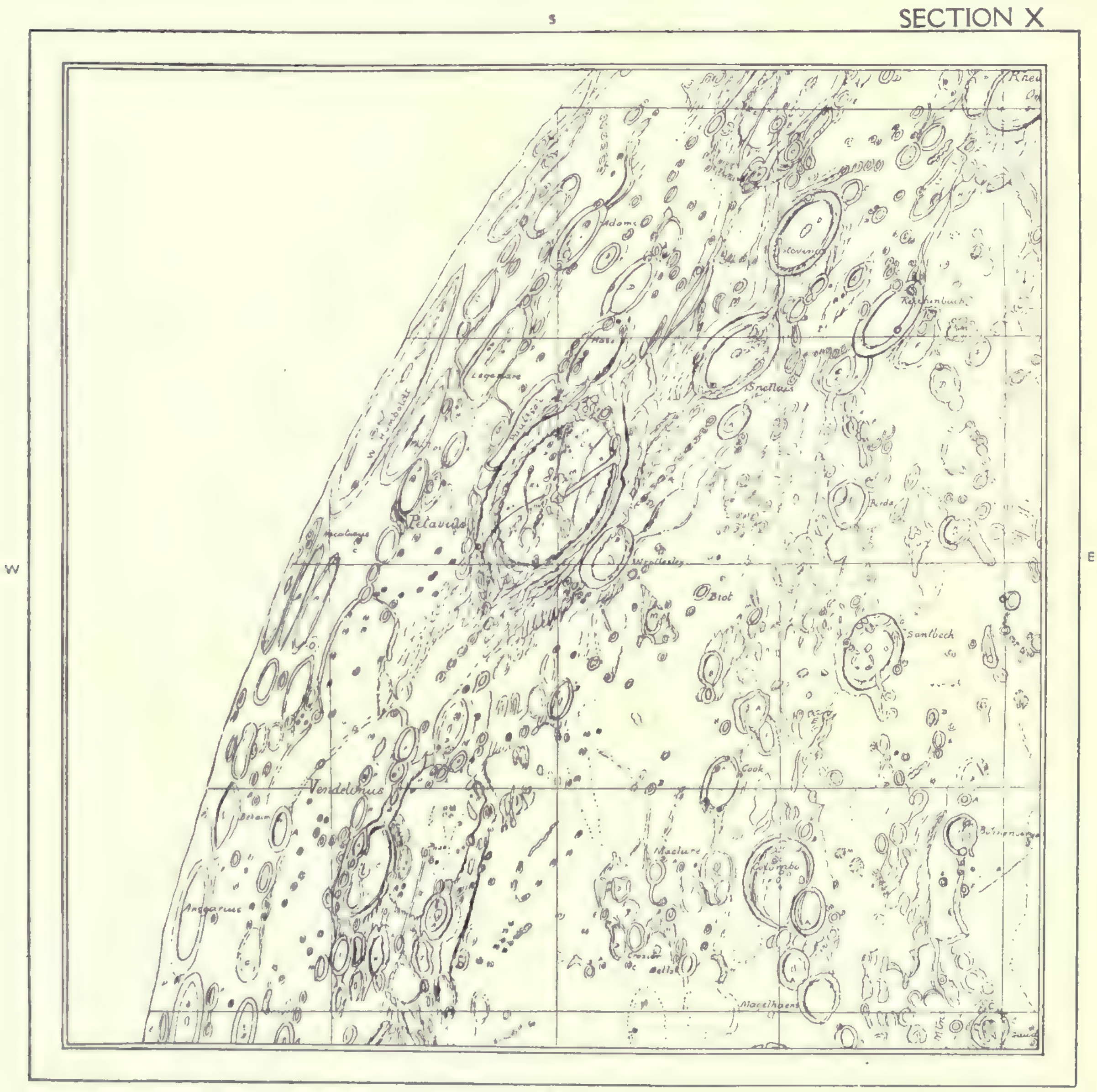
Stevinus. A large regular walled enclosure, similar in many ways to Snellius. It contains a large central peak. The southern crest rises about 4,000 feet above the interior.

Vendelinus. A large walled plain with most irregular ramparts. The floor is comparatively smooth, but contains a large number of craterlets, and a fine cleft running N. from the centre. There are several large ring plains associated with Vendelinus and found on its borders.

Wrottesley. A ring plain abutting on Petavius, with fine lofty linear walls rising to 9,000 feet above the interior. It contains a double-peaked central mountain.

SECTION XI.

The Moon's equator runs across the centre of this section. It contains the whole of the M. Fecunditatis.



Apollonius. 31 miles in diameter, with a fine cleft crossing the floor, and other minute details. The walls rise 5,000 feet above the interior.

Azout. A well-defined ring plain about 20 miles in diameter.

Cauchy. 8 miles in diameter, very bright and distinct at full. Mentioned for its association with the fine long cleft which cuts the plain on its Western side, and a long ridge on the plain on its E. side. Both very interesting objects.

Firminicus. A fine ring plain 38 miles in diameter, with ramparts rising 5,000 feet above the interior. The floor is level and dark in tone.

Goclenius. 30 miles in diameter, with irregular broken walls. The interior is dark and of the same shade as the surrounding *mare*. Goclenius is the source of an interesting system of clefts.

Guttemburg. A large irregular ring plain about 40 miles in diameter, the original rampart showing signs of erosion in many places. The interior contains interesting details in the shape of ruined rings, mountain peaks and clefts, which traverse it and extend far beyond the N.E. boundary.

La Peyrouse. A large well-defined ring plain near the limb.

Langrenus. A magnificent walled plain about 80 miles in diameter, with much-terraced walls rising to 10,000 feet above the interior. The floor of Langrenus is very bright, and contains among other things a large complex central mountain.

Langrenus would compare with Copernicus if it were as well placed on the disc.

Maclaurin and *Webb* are two ringed plains calling for no particular comment.

Messier and *Messier A.* Two small rings which have been suspected of change. They vary in size and appearance from night to night in each lunation. Two white rays diverge from A.

Mare Fecunditatis. The largest of the seas in the Western half, containing about 160,000 square miles.

Neper. A great mountain-walled plain close to the limb. Has a central peak and a number of ridges on the floor.

Pyrenees Mountains. A fine range of mountains to the E. of Goclenius, with peaks rising on the N. to about 12,000 feet and on the S. to over 6,000 feet.

Secchi. A small crater ring with wall open to the S. and much worn down by erosion.

Schubert. A large elliptical ring, too near the limb to be well seen.

Taruntius. A fine walled plain : the rampart is low and the interior appears to have been partly filled up with an outflow of lava. There are many partly destroyed rings in the neighbourhood.

SECTION XII.

Contains a number of interesting objects, including the well known Mare Crisium.

Alhazen. A ring plain on the western side of M. Crisium.

Berosus. A large elliptical ring with a central mountain.

Berzelius. An inconspicuous ring plain of no importance.

Bernouilli. A small ring plain with a feeble central peak.

Burckhardt. A ring plain N. of Cleomedes notable for the curious ear-shaped enclosure on either side of it.

Cleomedes. A large and interesting walled plain 80 miles in diameter, with broad and massive ramparts rising to 9,000 feet on the W. It contains a fine system of delicate clefts associated with craterlets.

Condorcet. A large ring plain about 45 miles in diameter, with a smooth floor free from detail.

Mare Crisium. One of the smallest and most conspicuous of the lunar *maria*, with well-defined mountain borders. The surface is said by some to show a green tinge. Its length is about 280 miles and its width 350 miles, with an area of about 78,000 square miles. On its surface are two craters—Picard and Pierce—a number of ridges and ruined rings, but few craterlets or clefts.

Gauss. A large mountain-walled plain about 110 miles in length, and close to the limb.

Geminus. A fine walled plain 54 miles in diameter with high walls rising 15,000 feet above the interior. Contains a central peak sometimes seen as a crater.

Macrobius. A fine walled plain about 41 miles in diameter, with bright terraced walls rising from 10,000 to 13,000 feet above the interior, which contains a low compound central mountain.

Eimmart. A ring plain 30 miles long, with peaks on its walls rising to great heights.

Hansen. A deep ring plain with terraced walls and a small central mountain.

Hahn. A fine ring plain near the limb. Contains a central peak.

Oriani. An irregular ring plain on the E. side of Plutarch.

Plutarch. A ring close to the limb with a central mountain and terraced walls.

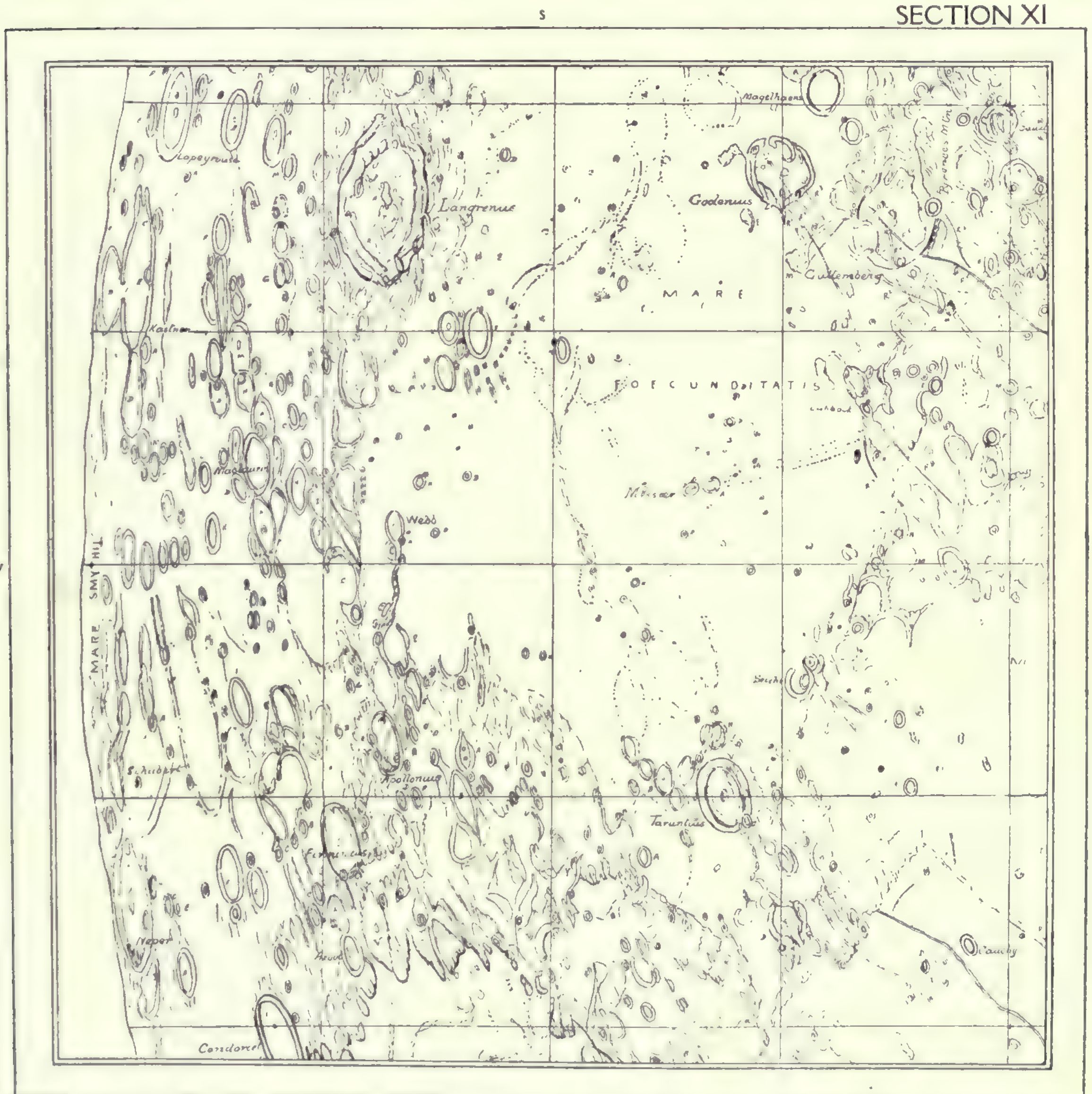
Proclus. A small crater ring noted as being one of the brightest spots on the Moon. The floor, however, is not so bright on the walls; several bright rays emanate from this formation.

Seneca. A ring of some size near the limb, but of no particular interest.

Tralles. A ring outside the N.E. wall of Cleomedes. Has three curved ridges on the interior.

SECTION XI

S



W

N

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SECTION XIII.

The principal formation in this section is *Messala*, a large walled plain close to the limb, which makes it difficult to observe. It is about 70 miles in length, with low walls. On the interior are a number of craters, some ridges and two clefts.

Schumacher. Some 35 miles in length, with a smooth floor.

Struve. A small ring plain remarkable for the dark area on which it stands.

Mercurius. A ring plain about 25 miles in diameter, with a smooth floor and small central mountain.

SECTION XIV.

The three most prominent objects are Atlas, Hercules and Endymion.

Arnold. A large ringed plain with broken walls, about 52 miles in diameter. The floor is smooth except for one small crater, as shown. Arnold is typical of a number of rings close to the limb and near the Moon's N. pole.

Atlas. A noble ring plain 54 miles in diameter, with massive walls rising on the E. to 10,000 feet, and on the W. to about 9,000 feet. On the interior are found specimens of nearly every formation known on the Moon : hills, craters, ridges, and a very fine system of delicate clefts. There are two dark spots which undergo regular changes during each lunation.

Burg. A circular ring plain 28 miles in diameter and containing a large bright central peak. There is a large enclosure to the E. of Burg which is crossed in two directions, N.S. and E.W., with several fine clefts—the main one is easy, the others difficult.

Cepheus. 27 miles in diameter, with steep terraced walls. The interior has two craterlets.

Chevallier. A large ring plain with very low walls. Seen best at sunrise or sunset.

De la Rue. A large plain about the same size as Endymion, but with low discontinuous walls. At its N. end are two small rings, Strabo and Thales.

Democritus. A deep regular ring plain, about 25 miles in diameter. It has a prominent central mountain.

Endymion. A fine walled plain, about 78 miles in diameter, and situated near the limb. Its walls are much broken. The dark interior contains only a few minute craters.

Franklin. A fine ring plain about 35 miles in diameter, with massive walls rising about 8,000 feet above the interior, which is very dark and smooth.

Gartner. A fine specimen of a ring plain, whose ramparts have been in part levelled by erosion.

Grove. A deep bright ring plain 17 miles in diameter. The walls rise to 7,000 feet above the interior, which contains an elongated central mountain.

Hercules. A fit companion to Atlas. About 45 miles in diameter, its massive ramparts rising to 10,000 feet above the interior, which contains little detail except a large crater and the remains of two smaller rings to the N. of it.

Mare Humboldtianum. A vast walled enclosure on the limb, and never satisfactorily seen.

Mason. An irregular craterlike depression.

Plana. A partially ruined ring plain, similar to Mason.

Oersted. A well-formed circular ring plain 27 miles in diameter.

Schuckburgh. A pear-shaped ring plain with low continuous walls.

SECTION XV.

This section is interesting, as showing the surface at the N. pole. Most of the objects situated near the limb in that direction call for little or no comment.

Alexander. A large lagoon-like depression about 65 miles in diameter, often overlooked.

The Alps. A noble range of mountains running in a great curve from Cassini to Plato. The peaks vary in height from 3,000 to over 8,000 feet, and here and there to greater elevation still. Midway along the range is a massive mountain named Mont Blanc, said to rise to 14,000 feet.

This range presents a fine spectacle when seen near sunrise or sunset. The mountainous country at the W. is traversed by a wide valley, known as the great Alpine Valley, the finest of its class on the Moon, about 75 miles in length and from 4 to 6 miles in width.

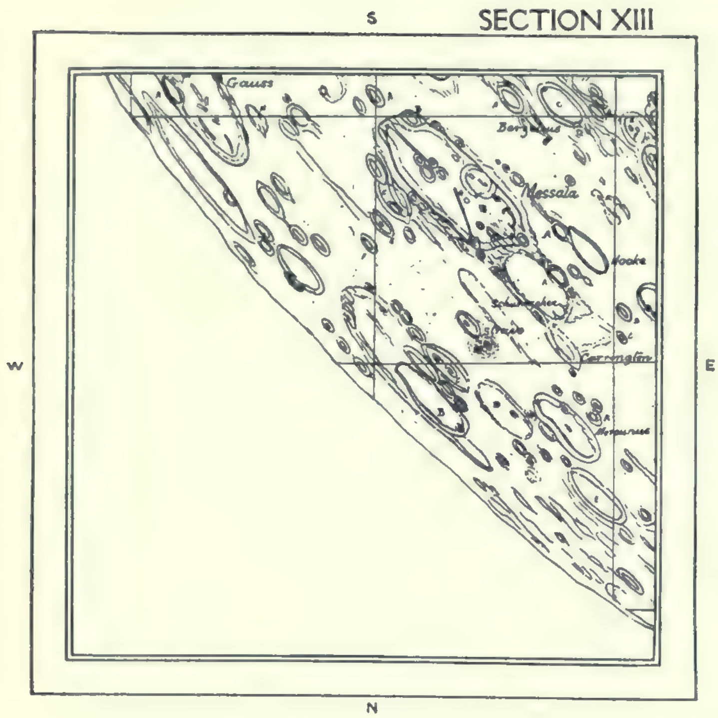
Archytas. A conspicuous ring plain 25 miles in diameter on the margin of the M. Frigoris. Two ruined ring plains, P and L, will be found to the W.

Aristoteles. A magnificent ring plain about 60 miles in diameter, with massive ramparts fairly uniform in height, and rising about 11,000 feet above the interior. A large number of ridges radiate from the walls to long distances.

Birmingham. A large irregularly-shaped area, very similar to W. C. Bond, J. J. Cassini, and Barrow, none of which objects have been exhaustively observed.

Calippus. A bright ring plain in the Caucasus Mountains. In contact with the E. wall is a fine mountain peak A, rising 18,000 feet, and near it a ridge B rising 13,000 feet.

SECTION XII



Cassini. A ring plain 36 miles in diameter, with low broad walls. The whole is invisible at full Moon. The interior contains a large crater and several imperfect rings and craterlets.

Egede. An obscure ring plain 22 miles in diameter, whose walls have been reduced to about 400 feet in height.

Eudoxus. Smaller, but of same type as Aristoteles, about 45 miles in diameter, with massive, lofty, and much-terraced walls. The interior contains a number of isolated mountain masses. On the small plain to the E. are two clefts.

Fontenelle. A fine ring plain on the margin of the M. Frigoris, 22 miles in diameter.

Goldsmidt. A large enclosure 50 miles in diameter. It is situated near to the N. pole, and the Moon's central meridian passes through it at its Western end.

Kirch. A small bright crater ring, almost identical in size with P. Smyth.

Pico. A fine example of an isolated mountain, said to rise from 7,000 to 9,000 feet above the plain—very bright.

Piton. A similar object to Pico. 30 miles to the S. is another mountain mass M.

Plato. One of the most interesting and best-observed objects on the Moon's surface. This fine lagoon-like enclosure, about 60 miles in diameter, has walls rising on the average 3,000 to 5,000 feet above the interior. On the W. wall are three high peaks which cast long, tapering shadows across the floor at sunrise. The dark interior contains a large number of craterlets, which have been charted, most of which are only visible in large telescopes. There is an interesting system of bright markings also, which has had much attention given to it.

Teneriffe Mountains. Consist of four isolated masses. They are not quite so bright as Pico.

Theaetetus. A well-formed ring plain S. of Cassini. The floor is depressed 7,000 feet below the surrounding crest. It is uncertain if there is a central peak.

SECTION XVI.

The most interesting object is the Sinus Iridum, a great bay in the M. Imbrium. The distance between the two headlands, Prom. Heraclides and Prom. Laplace, being about 135 miles. The surface level is only disturbed by some ridges and a few craterlets. The mountains bordering it on the N. and E. sides rise in places from 15,000 to 20,000 feet above the plain.

Condamine. A ring plain, about 23 miles in diameter, with rather low walls ; the interior contains several peaks.

Bianchini. A ring plain, 25 miles in diameter, with terraced walls, rising about 8,000 feet above the interior, which contains a small central mountain.

Bouguer. A bright ring plain about 15 miles in diameter with a smooth interior.

Harpalus. A fine ring plain said to be one of the deepest on the Moon's surface, the crest rising about 16,000 feet above the interior

Helicon. A ring plain about 15 miles in diameter and about 4,500 feet deep.

Herschel, J. A large irregular enclosure about 90 miles in diameter, similar in type to South and Babbage.

Horrebow. 15 miles in diameter with bright continuous wall.

Leverrier. Similar in type to Helicon, and probably formed at the same time. It has steep terraced walls on the inner side.

Louville. A rhomboidal depression more than 25 miles long.

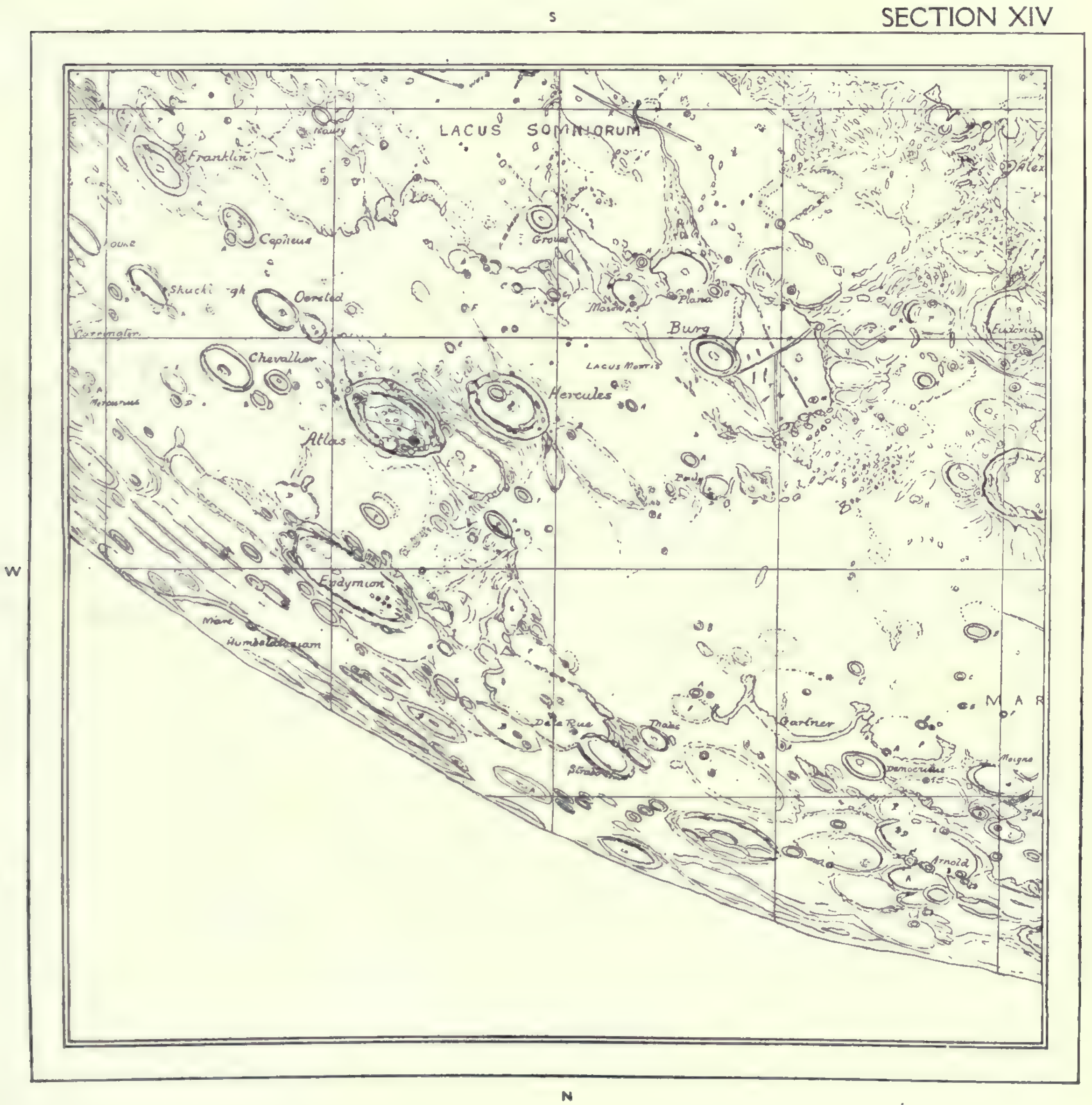
Maupertuis. An irregular-shaped depression with incomplete walls.

Mairan. A fine ring plain with terraced walls 25 miles in diameter. The rampart rises about 15,000 feet above the interior.

Robinson. A small ring plain about 15 miles in diameter, very deep and bright.

Sharp. A fine regular ring plain 24 miles in diameter, with walls rising about 9,000 feet above the interior, which contains a central mountain.

Straight Range. A very compact regular line of peaks, with a length of about 45 miles.



SECTION XVII.

Contains very few objects of interest in its small area, and these are all close to the limb and therefore not well placed for observation.

Gerard. A long elliptical regular ring plain.

Harding. A distinct regular ring plain with no particular features.

Repsold. A large irregular enclosure bound by ridges with a central crater.

Lavoisier. A large ring plain, elliptical through foreshortening. Contains no features of interest.

SECTION XVIII.

Contains very few formations of note, the most important and interesting of which is—

Aristarchus. Probably the brightest spot on the Moon. It is a deep distinct crater 29 miles in diameter, with walls rising 7,000 feet above the interior, which contains a fine central peak. To the N. is a large plateau and near it some fine clefts.

Briggs. A fine regular ring plain.

Cardanus. A fine ring plain 35 miles in diameter, elliptical through foreshortening, with walls about 4,000 feet above the interior. It is connected with Kraft by a long fine cleft or valley.

Harbinger Mountains. A group of isolated mountain peaks, and associated with them a number of ridges of about 400 feet in height.

Herodotus. 24 miles in diameter, interesting from the great winding valley which commences at its N. boundary and runs in a great horseshoe curve for many miles, being easily seen in a small telescope.

Herycinian Mountains. A range of peaks close to the limb and sometimes seen in profile.

Lichtenberg. A small isolated ring plain about 10 miles in diameter.

Kraft. A similar enclosure to Cardanus.

Marius. A ring plain 27 miles in diameter, with walls rising about 4,000 feet above the interior, which contains some feeble detail and some white spots seen near full.

Schiaparelli. A small ring plain without unusual features.

Seleucus. A ring plain 32 miles in diameter with high terraced walls rising about 10,000 feet above the interior.

Otto Struve. A vast enclosure near the limb, apparently once consisting of two parts, now joined together.

Ulugh Begh. A distinct elliptical ring close to the limb.

Vasco de Gama. A bright well-formed ring plain 51 miles in diameter with a central ridge.

Wollaston. A small bright ring plain with a level floor.

SECTION XIX.

Shows a great part of the Oceanus Procellarum, and consequently contains fewer formations than usual in such a large area.

D'Alembert Mountains. A chain of mountains near the E. limb. Can sometimes be seen in profile when the libration is suitable. Several peaks are said to rise to about 20,000 feet, but the whole range has not been adequately mapped.

Cavalerius. A great ring plain about 40 miles in diameter, with broken walls and peaks rising to 10,000 feet above the interior, which is of the same tone as the *mare*, and found with difficulty at full Moon.

Damoiseau. A curious ring plain containing a very large ring, and having its W. wall deformed by another (B). All the formations hereabout show signs of erosion.

Flamsteed. A small ring plain standing on the S. margin of a large enclosure, whose walls have been reduced very much by erosion.

Galileo. A small well-defined ring plain of no importance, lying N. of a large obscure enclosure P.

Grimaldi. A vast mountain-walled enclosure about 150 miles in diameter, and foreshortened into an ellipse. The walls are very discontinuous, and rise on the average to about 4,000 feet. The interior is probably the darkest spot on the Moon.

Hevel. A great mountain-walled plain about 71 miles in diameter, with steep continuous walls. The interior contains some fine clefts and a central mountain.

Kepler. A ring plain about 20 miles in diameter with walls of irregular height. It is one of the brightest objects on the Moon, and is the centre of a system of bright rays.

Hansteen. A fine ring plain similar in size to Billy, with irregular walls rising to about 3,700 feet. Contains a dark spot subject to variability. A large mountain mass is seen to the W.

Letronne. A vast obscure ring plain whose Northern ramparts have been almost entirely obliterated by erosion.

Lohrmann. A fine distinct ring plain, with several clefts on the plain outside and close to its W. wall.

SECTION XV

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Olbers. Similar in size to Cavalerius. It is the centre of a system of bright rays, as conspicuous as those associated with Kepler.

Reiner. A ring plain of normal type about 21 miles in diameter, with bright continuous walls terraced on the inner side, with peaks rising to 10,000 feet above the interior, which is darker than the surrounding surface ; contains a double central peak.

Wichmann. A small crater ring standing on the western arm of a large obscure enclosure, once a complete ring.

SECTION XX.

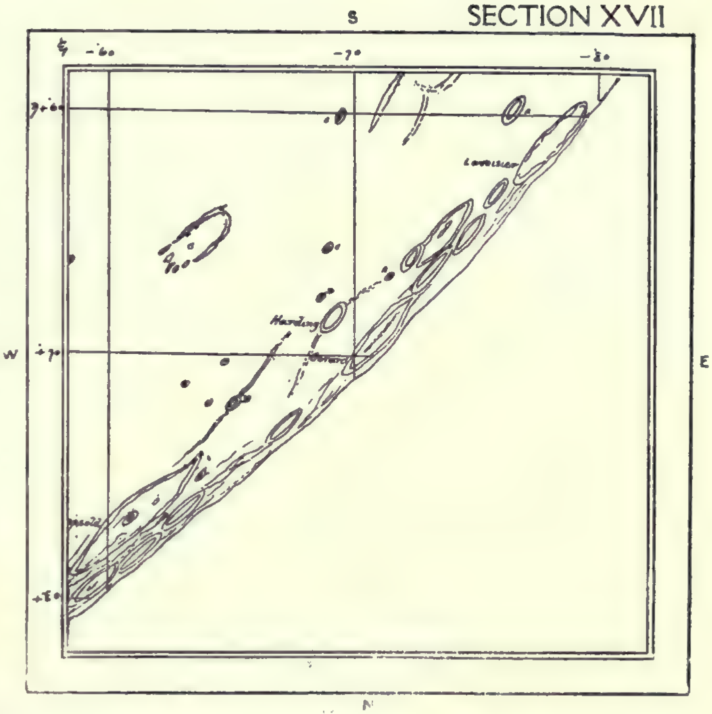
Shows a portion of the S.E. Section and is crowded with many objects of interest.

Billy. A fine ring plain 31 miles in diameter, remarkable for its dark interior, which appears free from irregularities of any kind.

Byrgius. A large irregular-shaped ring plain with a crater A on its W. wall, which renders it more easy of identification.

SECTION XVI

SECTION XVII



Cavendish. A complex ring plain about 32 miles in diameter. Its W. wall is disturbed by several crater-like depressions.

Cruger. 30 miles in diameter. Remarkable for the darkness of its interior under all angles of illumination.

Eichstadt. About 30 miles in diameter, with a level floor free from detail.

Fourier. Another ring plain about 30 miles in diameter, with terraced walls rising to about 6,000 feet above the interior.

Fontana. A ring plain with low regular walls. Contains a central peak.

Gassendi. One of the finest and most interesting of all the walled plains. It is 55 miles in diameter. The walls on the S. have been reduced to mere banks. The interior contains a large variety of interesting objects, consisting of a complex central mountain, many craterlets and a number of clefts, all of which have received much attention from selenographers.

Lagrange. A large irregular walled plain with little or no detail on its smooth interior.

Mersenius. A fine ring plain 45 miles in diameter with broad terraced walls. The interior has a chain of craterlets running N. and S. Outside to the W. and S. are a number of interesting clefts, most of which are not difficult to see.

Piazzi. A large enclosure similar to Lagrange.

Rocca. An elliptical ring plain close to the limb, and therefore difficult to observe.

Sirsalis. A fine ring plain 20 miles in diameter with high regular walls. The interior contains a central peak. Just outside the W. wall is a fine cleft, one of the longest on the Moon's surface.

De Vico. A small distinct crater ring.

Zupus. A small ring plain about 12 miles in diameter with low walls.

SECTION XXI.

Bouvard. A large elliptical ring close to the Moon's edge, consequently not well placed for observation.

Ingharimi. A large conspicuous walled plain about 60 miles in diameter, with steep high walls, rising in one place to 12,000 feet. The interior contains several large craters.

La Croix. A distinct ring plain with steep continuous walls. Has a large crater ring on the interior.

Lehmann. A large ring plain with broken walls on the S., where there are two passes. The floor is said to be traversed by a longitudinal ridge.

Rook Mountains. A range near the limb, often seen in profile, some of the peaks rising to about 25,000 feet.

SECTION XXII.

Bailly. A vast enclosure close to the S.E. limb, about 160 miles in length, comparable to one of the smaller seas. Its walls are irregular in height and broken in places. The interior contains a number of craters; one (B) being of large size.

Bayer. A ring plain on the W. side of Schiller, with walls rising about 8,000 feet above the interior.

Bettinus. A fine ring plain with massive lofty walls rising 12,000 to 13,000 feet above the interior, which contains a fine central mountain, said to have two peaks.

Doerfel Mountains. A magnificent range lying almost wholly beyond the S.E. limb, and only to be well seen under favourable libration. Some of the peaks are said to rise to 26,000 feet.

Drebbel. 18 miles in diameter, with a floor devoid of detail.

Hansen. A fine deep ring plain on the limb in front of the Doerfel Mountains.

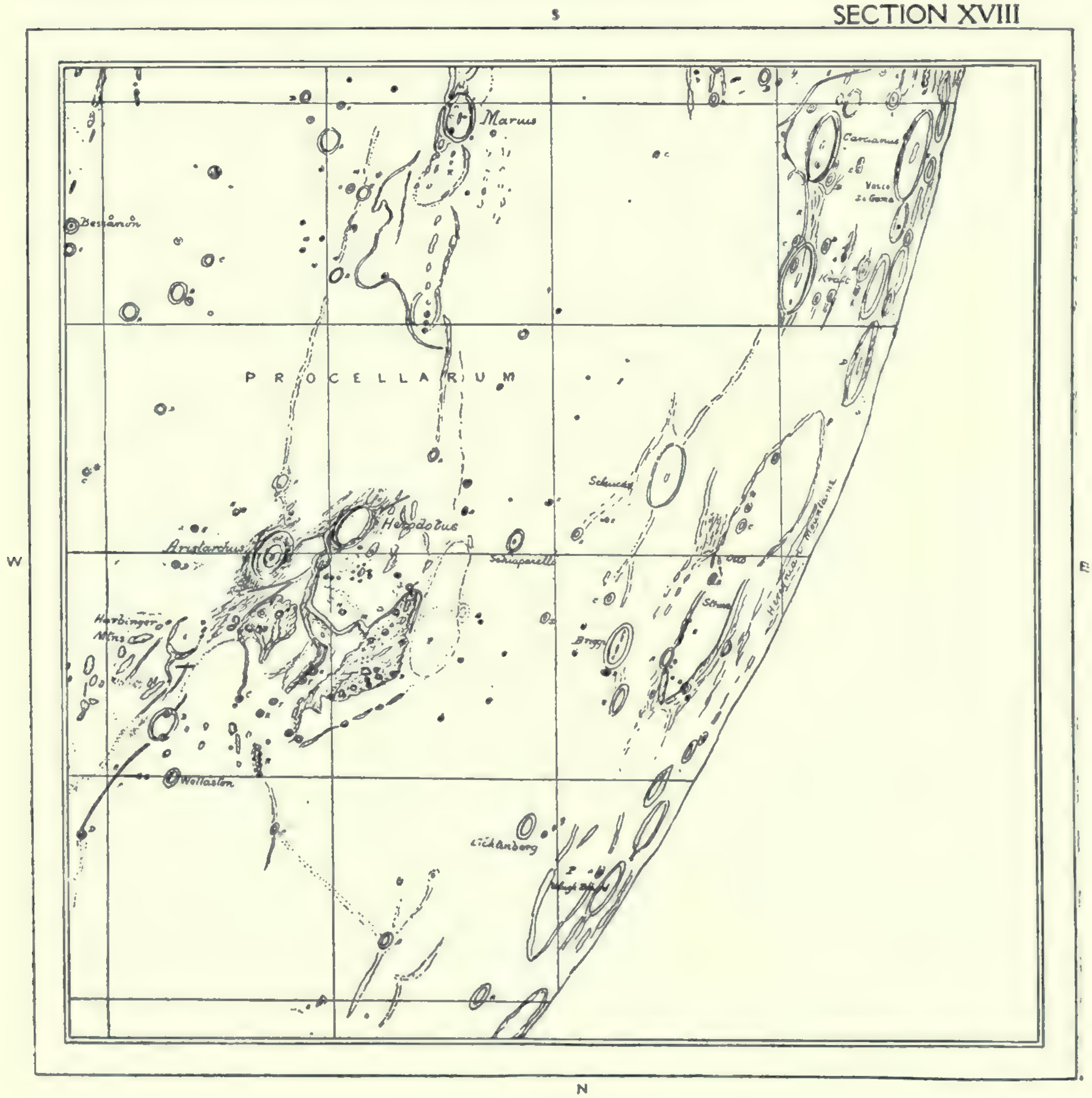
Hainzel. A large, most irregular enclosure, consisting of two large rings which have coalesced, with steep and lofty walls. The interior is very rough.

Heinsius. A large irregular enclosure whose original circular boundary has been deformed by two large craters, C and B.

Kircher and Wilson. Comprise, with Bettinus, a row of three fine walled plains.

Legentil. A large enclosure on the limb, difficult to identify.

SECTION XVIII



Longomontanus. A large mountain-walled plain about 90 miles in diameter, with irregular walls, one peak on the E. rising to 13,000 feet. The interior contains a multiple central peak. There is a large group of craters on the floor near the N.E. wall.

Phocylides. A large irregular-walled plain. The interior is quite smooth. At the Northern end of the ring is another smaller enclosure (B), separated from Phocylides by a chain of craters.

Scheiner. A very fine circular walled plain about 70 miles in diameter, with lofty walls. There are several ridges and craters on the interior.

Schiller. An elliptical walled plain said to be 112 miles in length, with a breadth of about 60 miles. The floor is very free from detail.

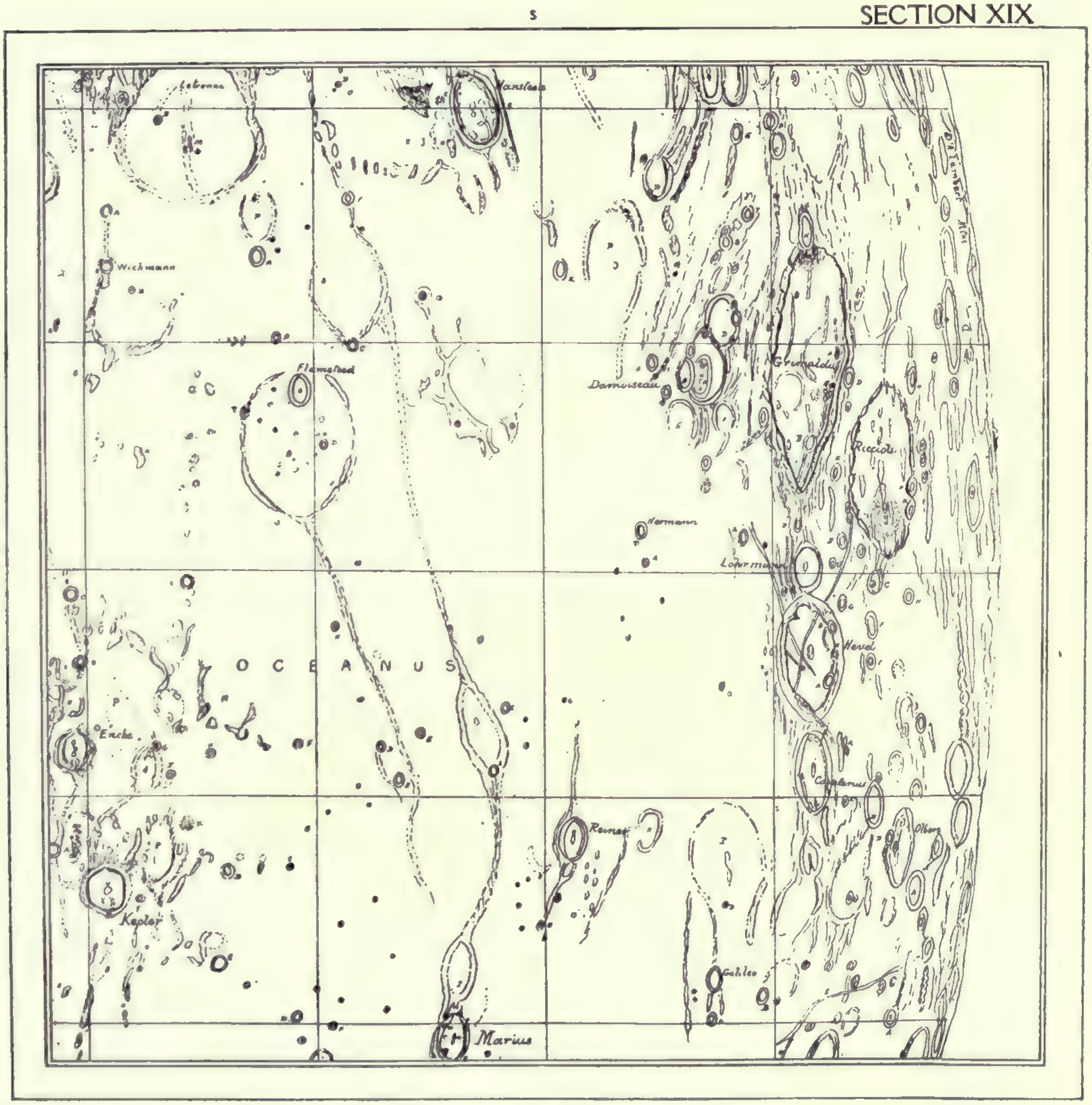
Segner. A very large irregular enclosure S.W. of Schiller, with very broken walls, rising only to 4,000 or 5,000 feet above the interior, which contains a large number of craterlets.

Schickard. A very fine large walled plain about 134 miles in length, with low walls rising on the

SECTION XIX

S

W



E

N

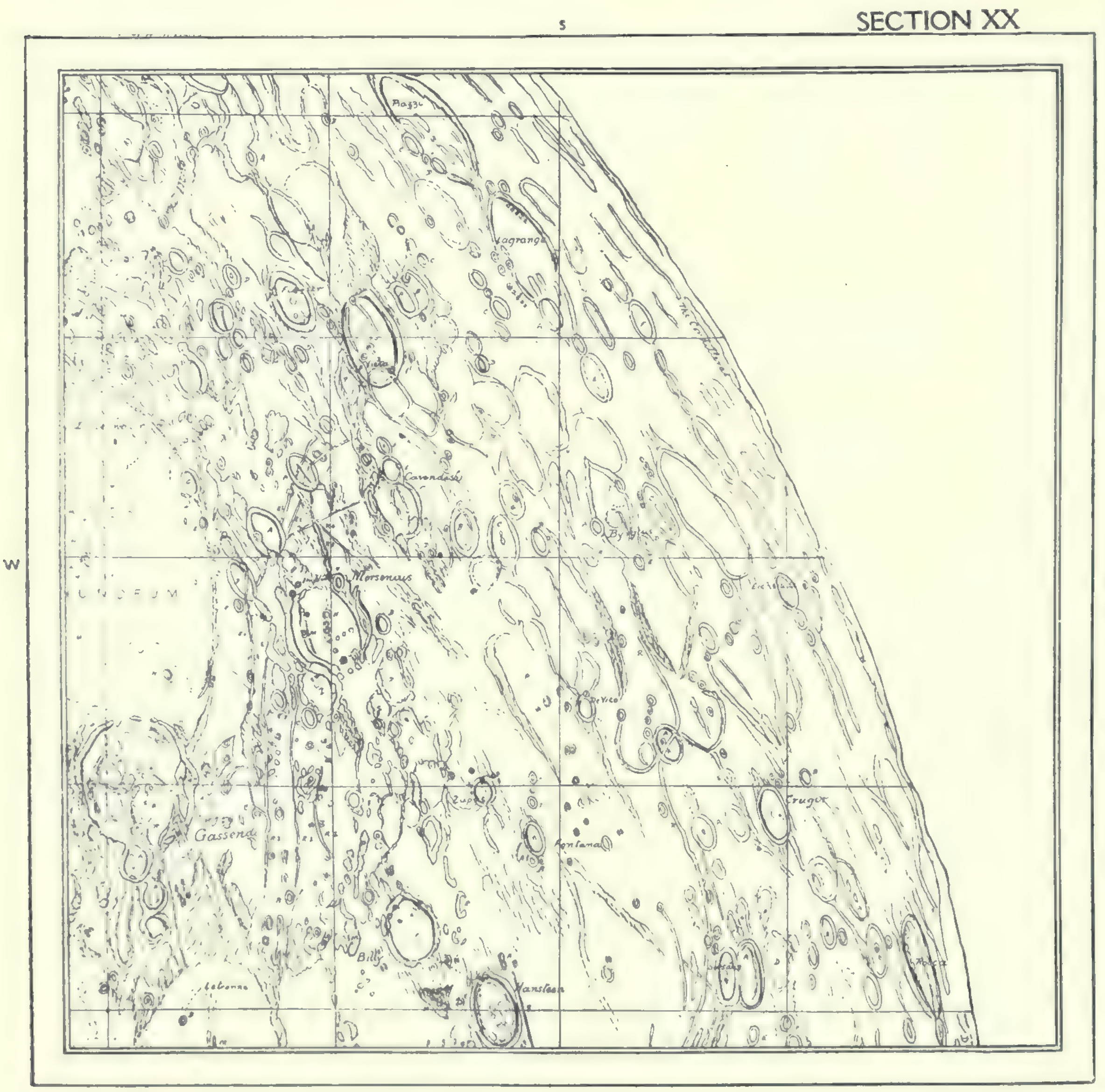
average to about 4,000 feet above the interior, which contains many objects of interest not yet properly mapped. There is a large dark area, occupying nearly the whole of the Northern half of the floor. Under the S.W. wall is a triangular patch of shade with a very sharp boundary, probably marking the site of a delicate cleft.

Wargentin. One of the most remarkable ring plains, as its interior appears to have been filled up almost to the height of the crest by lava in byegone times.

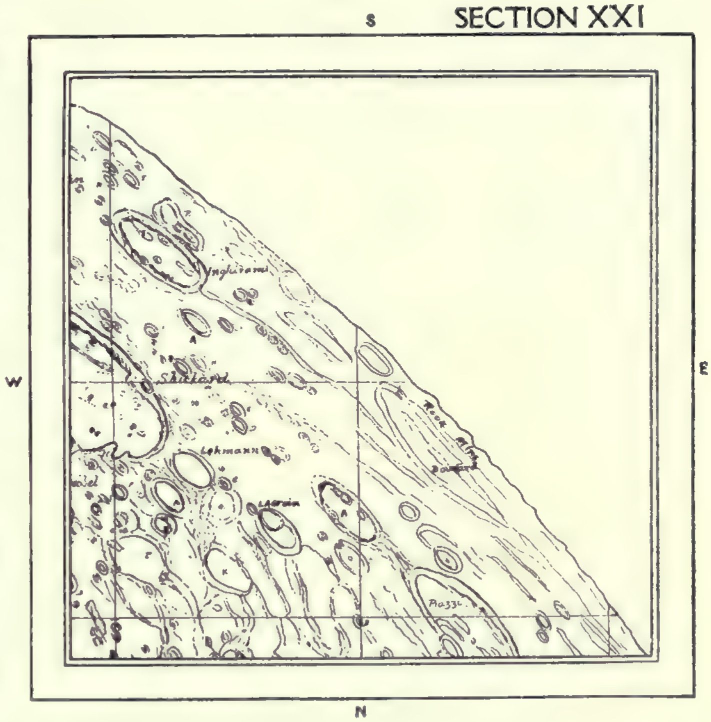
Zuchius. A ring plain with high massive walls rising in places to 10,000 feet above the interior, which contains a large central elevation and a crater ring.

SECTION XXIII.

This Section, which embraces a large district, including the S. Pole, is so very crowded with rings of all sizes and shapes that it is only possible to refer briefly to the principal formations.



SECTION XXI



Blancanus. A large walled plain with an interior depressed about 12,000 feet below its massive rampart, about 70 miles in diameter. The floor is level, with little detail.

Casatus. A large symmetrical ring plain about 45 miles in diameter. It is said to have on its massive wall three of the highest peaks in the third quadrant, the highest of which rises to about 22,000 feet above the interior. The crater (C) on the floor is 11 miles in diameter.

Clavius. The largest depressed mountain-ringed enclosure on the Moon's surface, about 150 miles in diameter, with massive walls, rising to an average of 12,000 feet above the interior. Presents a very fine spectacle at sunrise or near sunset. On the floor are many craters and crater rings, of which A and B are about 30 miles in diameter.

Clairaut. A large ring plain whose walls have been much deformed by the intrusion of two large rings on the S. side.

Cuvier. Nearly 50 miles in diameter, with high terraced walls rising in places to nearly 12,000 feet above the interior. The floor is devoid of notable detail.

Curtius. A magnificent walled enclosure about 50 miles in diameter. The floor is bare of detail except for a crater at the centre.

Deluc. A ring plain about 25 miles in diameter, to the S. of Maginus.

Faraday. A large ring plain whose walls have intruded on the interior of Stöfler.

Fernelius. Occupying a similar position to Faraday, but on the opposite side of Stöfler.

Jacobi. A large ring plain with regular walls. The interior contains a central group of craters.

Klaproth. A great irregular walled plain 65 miles in diameter. Its Southern wall has been destroyed by the intrusion of the N. wall of Casatus. The interior is very level.

Licetus. A large irregular walled enclosure much resembling Cuvier. Two other formations are associated with Licetus, marked B and C. There is a high mountain ridge in B, with craters on either side of it—a very fine object under a low sun.

Leibnitz Mountains. A great range on the limb and extending on each side of the S. pole. They present a remarkable sight when seen in profile, and some of the peaks are said to be the highest found on the Moon.

Lilius. A large ringed plain with high walls rising from 7,000 to 10,000 feet above the interior, which only contains a compound central mountain.

Maginus. A magnificent mountain-walled plain, comparable with Clavius, having a diameter, of about 120 miles. The interior contains several large crater rings, some ridges, and a number of craterlets, with also a compound central mountain.

Moretus. A large well-defined mountain-walled plain 75 miles in diameter, with massive ramparts rising 9,000 feet above the interior, which contains a fine compound central mountain rising about 7,000 feet. Beer and Mädler think this the highest central peak on the Moon.

Manzinus. A fine walled plain about 60 miles in diameter. The walls rise in places to 14,000 feet above the smooth interior. It is said to possess a feeble central peak.

Maurolycus. One of the finest walled plains on the Moon, about 72 miles in diameter, though some authorities make this much greater. The massive rampart rises to 14,000 feet on the W. and to 18,000 feet on the E. above the interior, which contains a complex central peak and other objects of interest.

Miller. 35 miles in diameter, with terraced walls rising 10,000 feet above the interior.

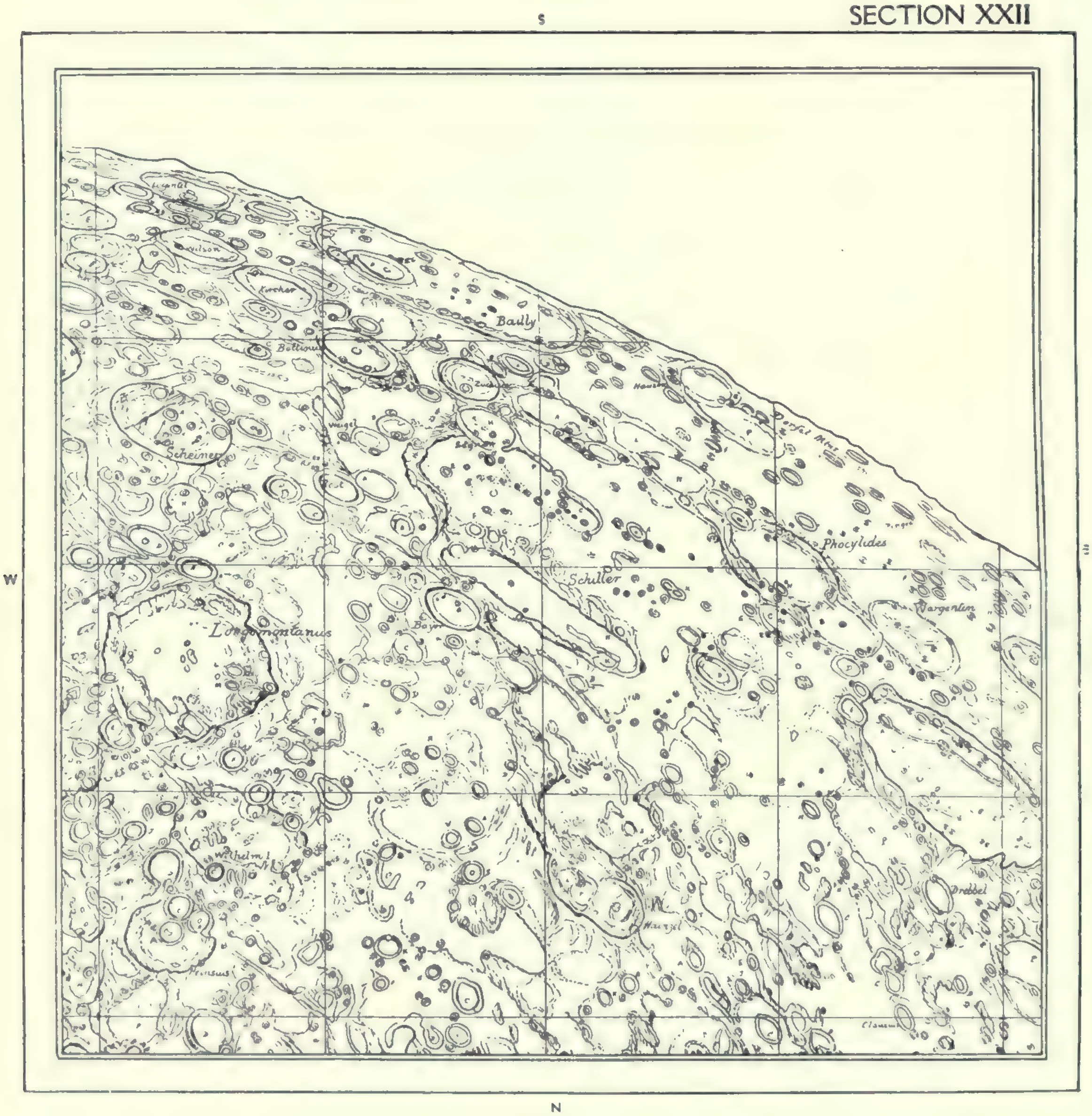
Nasireddin. 30 miles in diameter, with high terraced walls rising some 9,000 feet.

Newton. An immense oblong enclosure about 140 miles in length—is the deepest formation of its class on the Moon. One peak on the E. is said to rise no less than 24,000 feet above the interior, which is quite level. On account of its situation and great depth, neither the Earth nor Sun are ever visible from some parts of its interior.

Orontius. A large irregular walled plain whose original ramparts have been greatly deformed. The interior contains some large ruined rings, E and F in particular.

Pentland. A fine deep ring plain 50 miles in diameter, with broad, high-terraced walls. Has a double-peaked central mountain.

SECTION XXII



Sasserides. A large irregular enclosure. Its floor is crossed by many parallel ridges and crater chains, which seem to have originated by explosive forces in Tycho.

Saussure. About 30 miles in diameter with high terraced walls. The interior shows a curved line of craters.

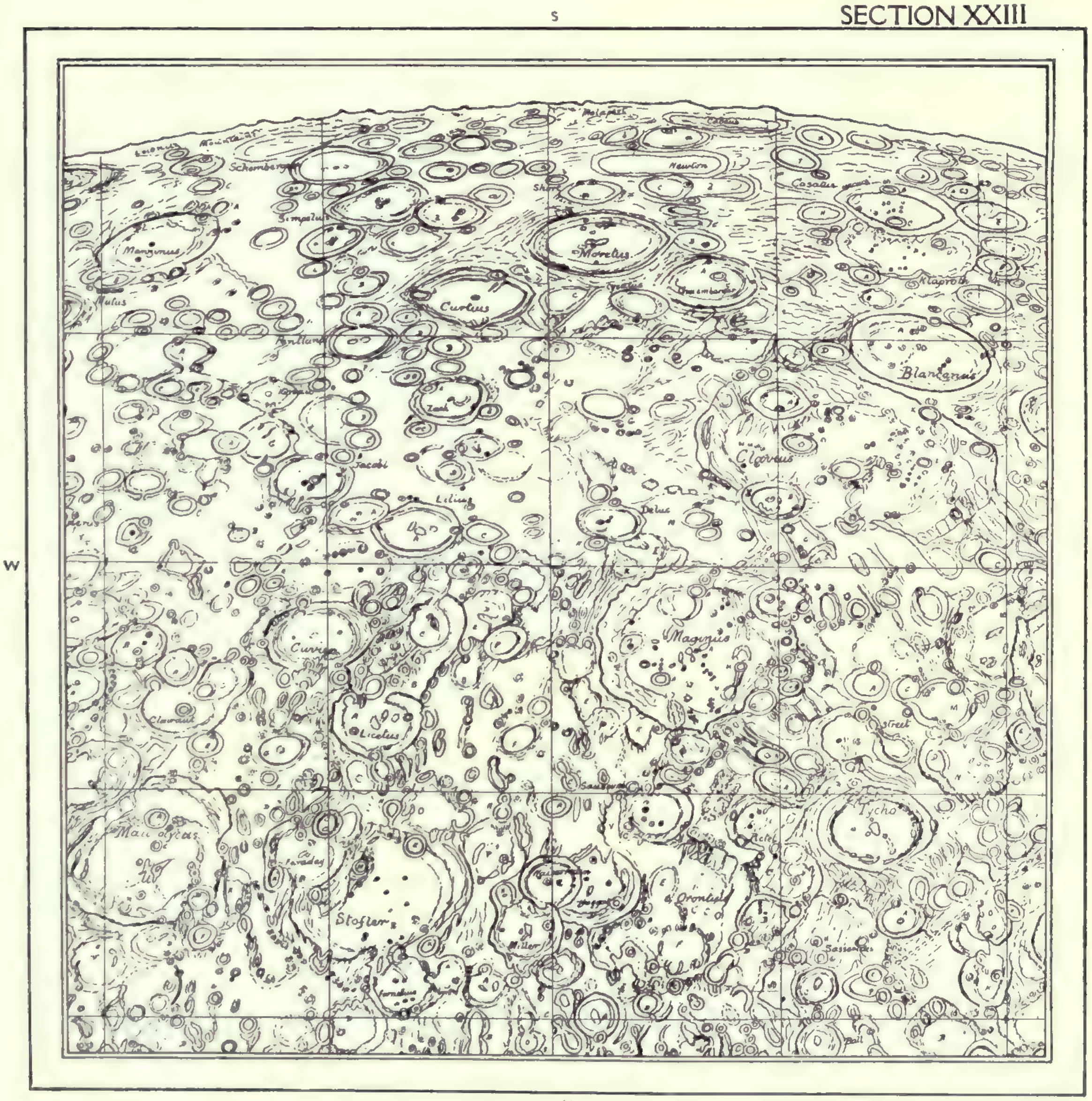
Schomberger. A long irregular walled plain with a rugged high rampart.

Simpelius. Very similar to Schomberger.

Tycho. Well described as the metropolitan crater of the Moon, 55 miles in diameter with massive terraced walls rising to about 12,000 feet. On the interior is a fine central mountain consisting of several peaks. Tycho is the centre of the finest system of bright rays on the Moon. These radiate from it as a focus and extend for great distances.

Zach. A massive mountain-walled plain with ramparts very much distorted from the circular form in places.

SECTION XXIII



SECTION XXIV.

Here we again have a vast concourse of ringed formations of all sizes and shapes, and only the principal objects can be described briefly on account of lack of space.

Bacon. 40 miles in diameter, with massive walls rising in one place to 14,000 feet above the interior, which is level and devoid of notable detail.

Barocius. 51 miles in diameter, with massive walls rising to 12,000 feet above the interior, which contains fragments of ruined rings.

Biela. A fine ring plain about 45 miles in diameter. Contains a central hill and a crater.

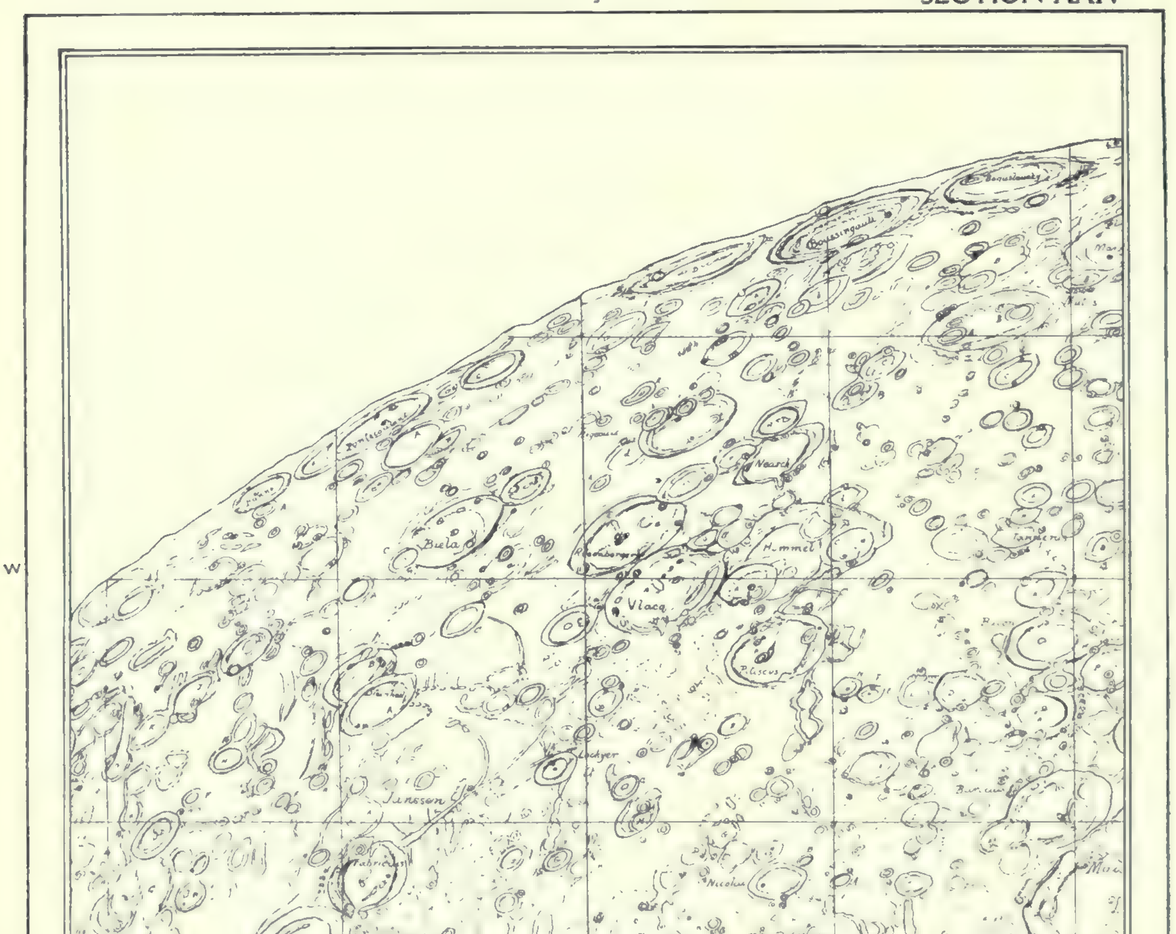
Boguslawsky. A large walled plain near the limb. The floor is free from notable detail.

Boussingault. A large mountain-walled plain about 80 miles in diameter, close to the limb. It is remarkable from the fact that its rampart is double, one ring within another.

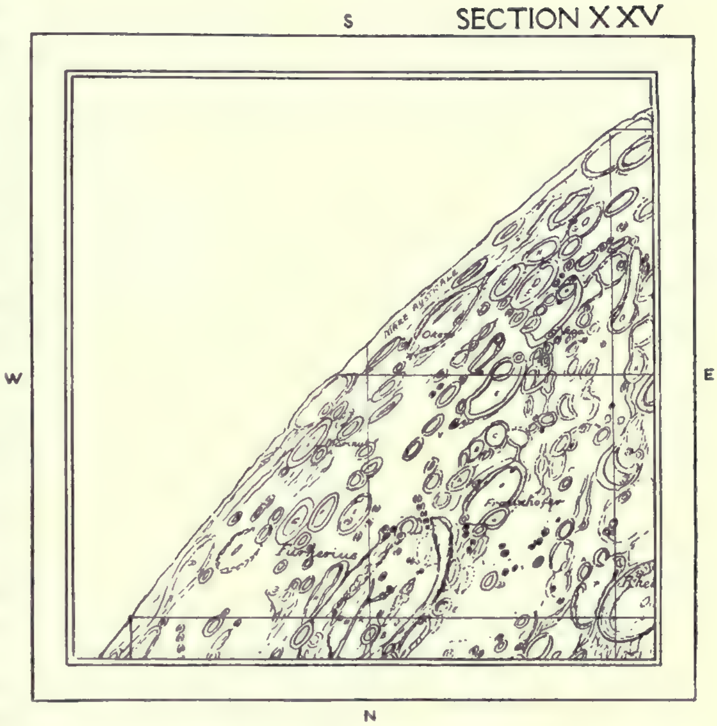
Buch. 30 miles in diameter with moderately high walls. The floor is free from detail.

SECTION XXIV

S



SECTION XXV



Fabricius. A fine deep ring plain 50 miles in diameter, with walls rugged and much terraced. There is a break or pass in the N. wall.

Hommel. A large irregular enclosure about 80 miles in length. Its ramparts are broken by several large crater rings.

Jannsen. A large hexagonal enclosure about 120 miles at its greatest width. The interior contains a large amount of interesting detail, including curved clefts of considerable length and width.

Mutus. A fine ring plain 46 miles in diameter, with regular walls rising 12,000 feet above the interior.

Nearch. 40 miles in diameter with continuous walls.

Metius. 50 miles in diameter, with lofty walls and a level floor containing a few low ridges.

Pitiscus. A fine ring plain 52 miles in diameter with continuous walls rising to 10,000 feet above the floor on the W. There is a mountain and a crater at the centre.

Pontecoulant. A large mountain-walled plain more than 50 miles in diameter. Close to the limb.

Riccius. A large irregular enclosure 40 miles in diameter.

Rosenberger. A large ring plain abutting on Vlacq and about the same size, but with lower walls, and the interior of a darker tint.

Steinheil. A striking formation consisting of two large ring plains with overlapping walls.

Vlacq. A fine deep regular ring plain 55 miles in diameter, with lofty walls. The interior contains a fine central mountain.

SECTION XXV.

Fraunhofer. A regular ring plain 30 miles in diameter. The walls rise about 5,000 feet above the interior, which possesses no notable detail.

Furnerius. A fine walled plain with complex ramparts rising to nearly 11,000 feet. The interior contains many objects of interest, including ridges, clefts and craterlets.

Marinus. A ring plain close to the limb with a small central peak.

Oken. A large ring plain close to the limb with low and broken walls.

Vega. A large ring plain notable for the destruction of its W. wall by a chain of large craters.

INDEX OF FORMATIONS.

With references to Section of Lunar Map.

PART II.

CHARTS OF THE CONSTELLATIONS.

The general forms and relative positions of the various star-groups, as they appear in the sky, are best learnt by reference to the monthly maps. These latter are sufficiently accurate for the bare purpose of identification, for which they are designed; but for a more exact representation of each constellation the reader should refer to the small-scale key-maps on pages 876 to 881. On these maps the co-ordinates of Right Ascension and Declination are roughly indicated, while the days of the month marked in the margin show what stars are on the meridian at about 9 o'clock in the evening of the date named. Since, as explained in Chapter XIX, any given star comes to the meridian four minutes earlier each night (by Mean time), it is a simple matter to find what constellations are due south at any other hour of the night by adding 15 days to the date for each hour after 9 p.m. or subtracting a similar amount for each hour before that time. Thus, for example, a constellation that is shown by the key-map to be on the meridian at 9 p.m. on September 20 will have passed westwards by 10 p.m. and be replaced by the stars opposite the date October 5. At 8 p.m. on the same night the meridian will be occupied by constellations corresponding to the date September 5, and so on.

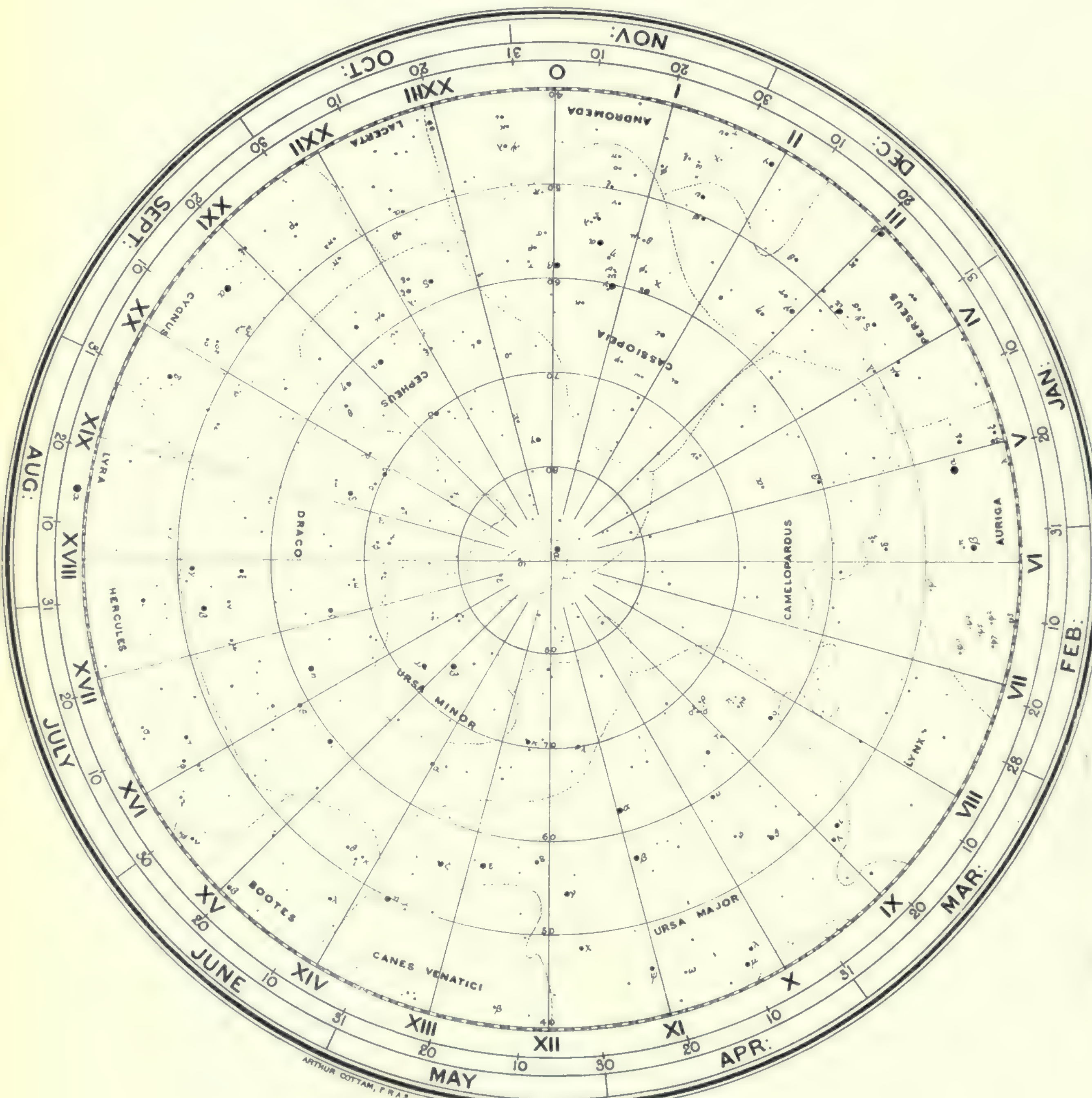
The thirty-six large-scale charts which follow the key-maps are not intended primarily as a guide to the recognition of the constellations, but rather for the use of the observing amateur who possesses a telescope of small or moderate size. Originally executed by the late Mr. Arthur Cottam, F.R.A.S., and published by him in 1891, they were designed for use in conjunction with the Rev. T. W. Webb's *Celestial Objects for Common Telescopes*, showing the positions of all the objects mentioned in the fourth edition of that work, and many more besides. The charts have been chosen for inclusion in the present work as being in many respects the most complete and accurate of their kind, and as having been proved by experience to be admirably suited to the purposes for which they were designed. They have, however, the defect of stopping short at 40° South Declination, thus leaving uncharted a circle of 50° radius with its centre at the South Celestial Pole. This is of no moment to those living in high and mid-latitudes of the Northern Hemisphere, but observers farther south than about 40° north latitude will find it necessary to supplement these charts by the purchase of an atlas that covers the entire sky. That of Norton may be specially recommended, as having been designed for the same purposes as the charts now before us.

The order adopted in the arrangement of these is part of a definite scheme, devised by their author, whereby the constellations are gradually linked up with one another from the common starting point of the north polar regions, which are shown on Chart No. 1. The numbers enclosed in small circles outside the borders of each chart give a clue to the method adopted in this linking-up, as they represent the numbers of the particular maps which cover the region of the sky immediately adjoining the chart on the side indicated. This arrangement was intended as a further help towards learning the relative positions of the various star-groups, and has here been retained to avoid confusion. However, in the case of charts of this sort, designed for use with the telescope, it is more usual to arrange them either in order of Right Ascension, or in alphabetical order, to facilitate the rapid finding of objects from published lists and catalogues. The former arrangement is adopted in the lists of objects which follow; but, for the benefit of those who wish to use the maps in conjunction with Webb's *Celestial Objects*, where the constellations are taken in alphabetical order, the subjoined list, so arranged, gives the necessary reference to the chart required in each case.

LIST OF CONSTELLATIONS.

	Chart No.		*Chart No.*		*Chart No.*
Andromeda	10	Aries	13	Camelopardus	3
Aquarius	36	Auriga	14	Cancer	17
Aquila and Antinöus ...	33	Boötes	20	Canes Venatici	9

KEY MAP No. 1.



Epoch 1890.

List of Constellations.—*continued.*

	Chart No.		*Chart No.*		*Chart No.*
Canis Major	28	Gemini	16	Puppis	28
Canis Minor	25	Hercules	21	Pyxis	28 and 30
Capricornus	36	Hydra	30 and 31	Sagitta	23
Cassiopeia	4	Lacerta	6	Sagittarius	35
Cepheus	2	Leo	19	Scorpio	34
Cetus	27	Leo Minor	18	Scutum Sobieskii ...	32
Columba ...	26 and 28	Lepus	28	Serpens	32
Coma Berenices ...	9	Libra	34	Sextans	30
Corona Borealis ...	20	Lynx	7	Taurus	15
Corvus	31	Lyra	21	Taurus Poniatowskii ...	32
Crater	31	Monoceros	25	Triangulum	13
Cygnus	22	Ophiuchus	32	Ursa Major	8
Delphinus	23	Orion	24	Ursa Minor	1
Draco	1	Pegasus	11	Virgo	29
Equuleus	11	Perseus	5	Vulpecula et Anser ...	23
Eridanus	26	Pisces	12		

As already indicated, the charts are intended to assist the amateur observer in finding or identifying objects that may be studied to more or less advantage with telescopes of moderate size. The beginner, who has recently purchased a telescope, and who wishes to explore with it the "show" objects of the heavens, should first consult the key-maps in order to find out what constellations are on or near the meridian at the date and time when the observations are contemplated. Reference to the list just given will then enable him at once to turn up the chart covering the particular constellation in which explorations are to be made. Then, noting roughly the limits of Right Ascension included in the chart, he will know whereabouts in the list he should look for the description and exact position of the objects most worthy of his attention. Of these it is only possible to give here a few of the more striking and conspicuous, and even so some of them (especially certain nebulæ) may be found disappointing as seen through small instruments, and must not be expected to appear as in the photographs illustrating Chapter XIV. As explained in Chapter XX, clusters and nebulæ are, in general, best observed with fairly low powers, and nights should be chosen on which there is little or no moonlight. To insure the most satisfactory views, the eye should be allowed to rest in comparative darkness for several minutes before observations are commenced. In the case of very faint stars and nebulæ it will be found possible to make them appear somewhat more conspicuous by the use of what is known as "averted vision." This consists in directing the gaze, but not the attention, to a part of the field somewhat removed from (preferably just above) the object that is being observed. The image of the latter will now fall on a more sensitive portion of the retina of the eye, and the object will in consequence appear brighter than when seen direct.

For each cluster or nebula in the list here given the N.G.C. number is placed first. But, as the construction of the charts was begun before the appearance of the New General Catalogue of Dreyer, the same objects appear upon them under different synonyms. Therefore, to assist in identification, such synonyms are inserted in brackets after the N.G.C. number. The significance of each is explained in the following list :—

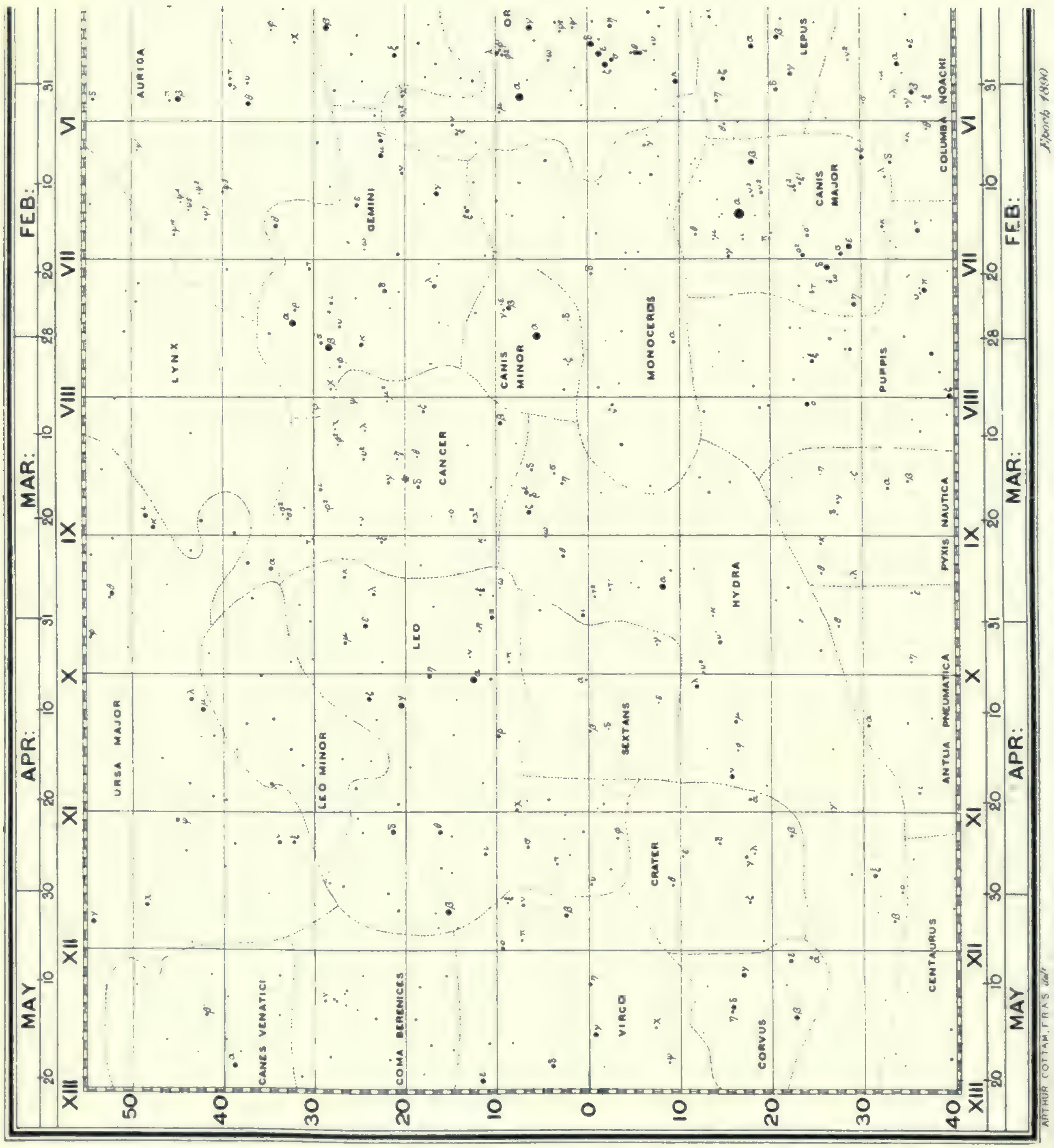
Key to Lettering of Charts.

Stars.

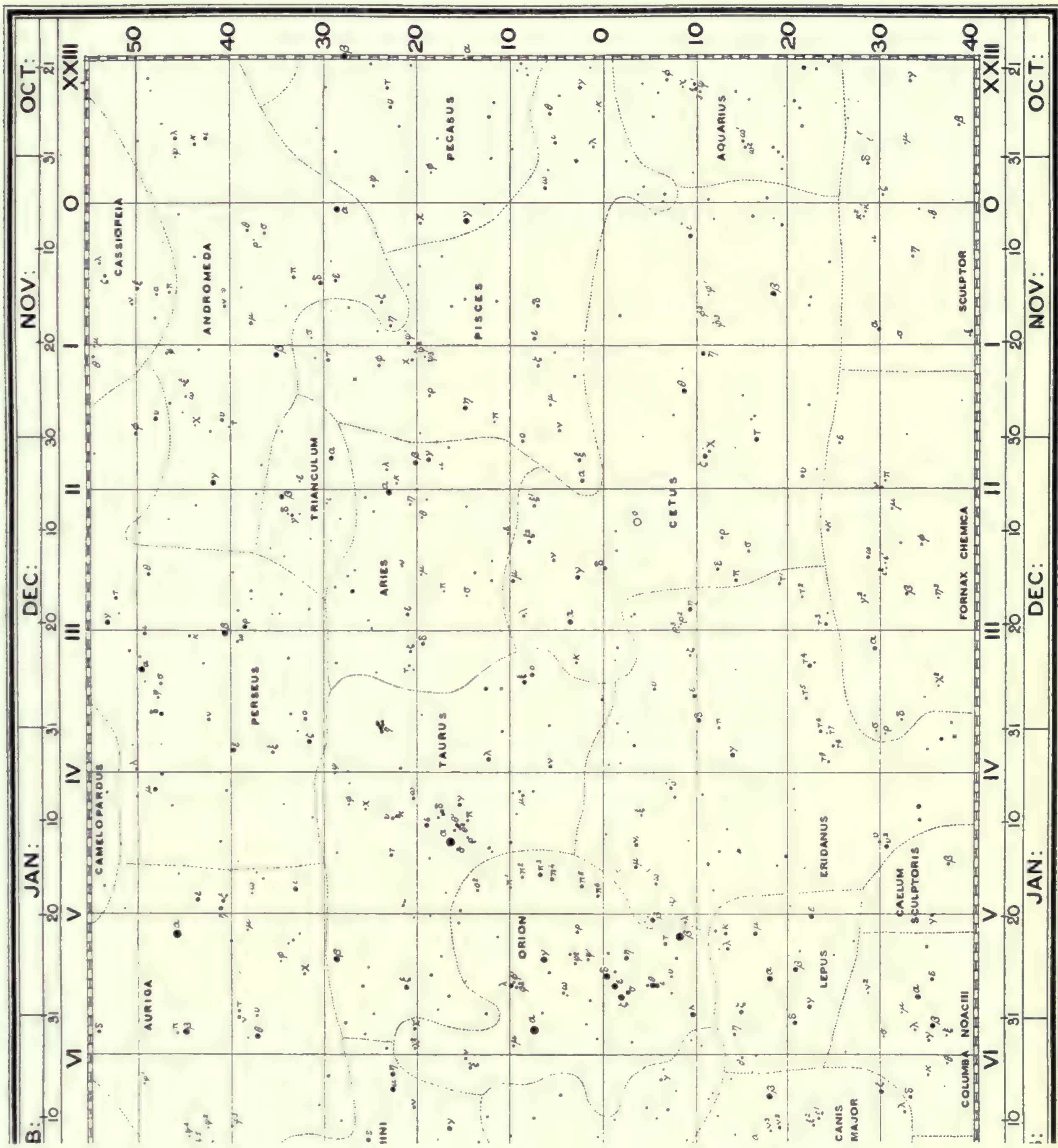
Greek letters :—

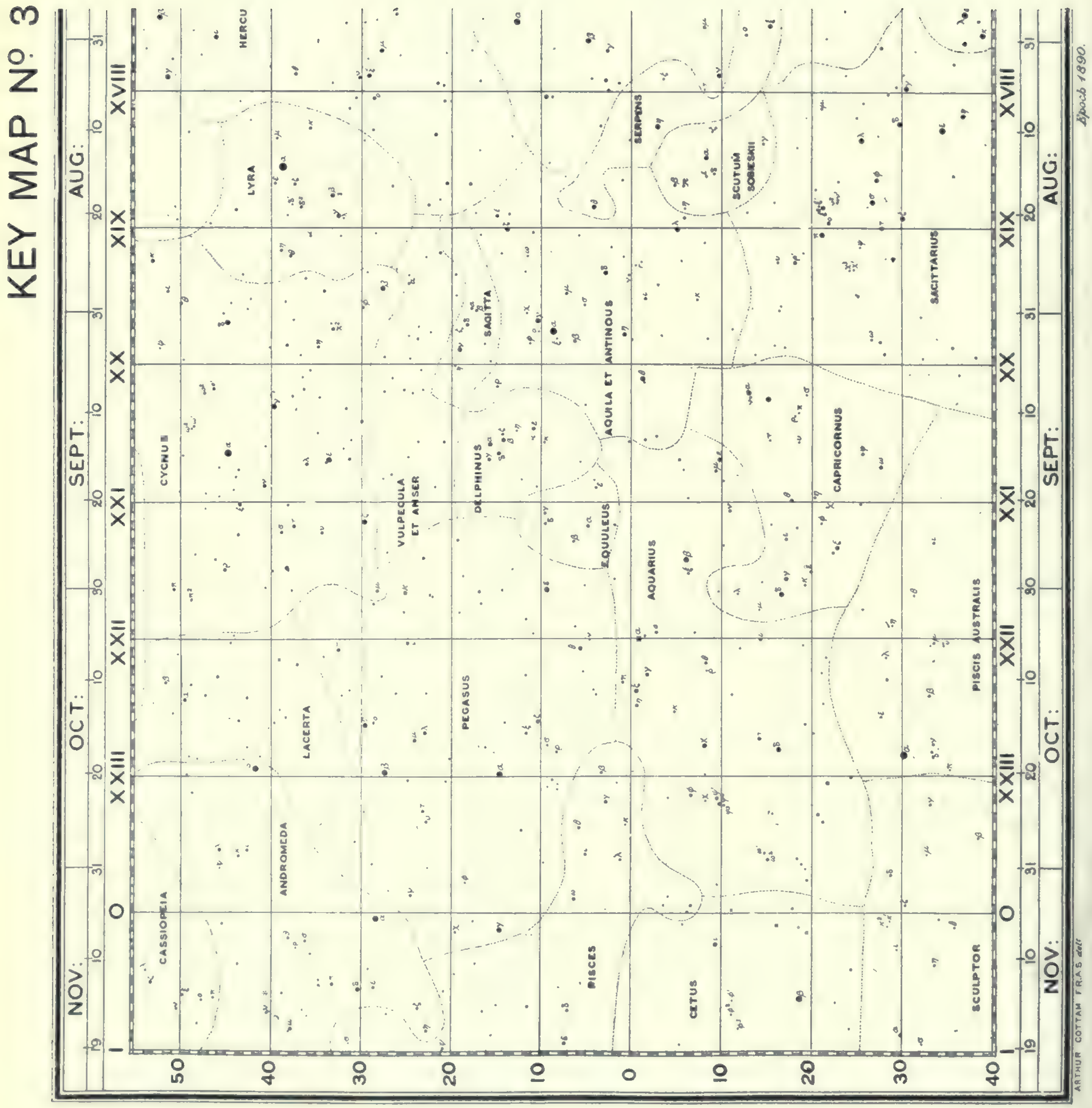
Bayer's designations, applied to the brighter stars of a constellation ; not necessarily in order of brightness or Right Ascension.

KEY MAP No. 2

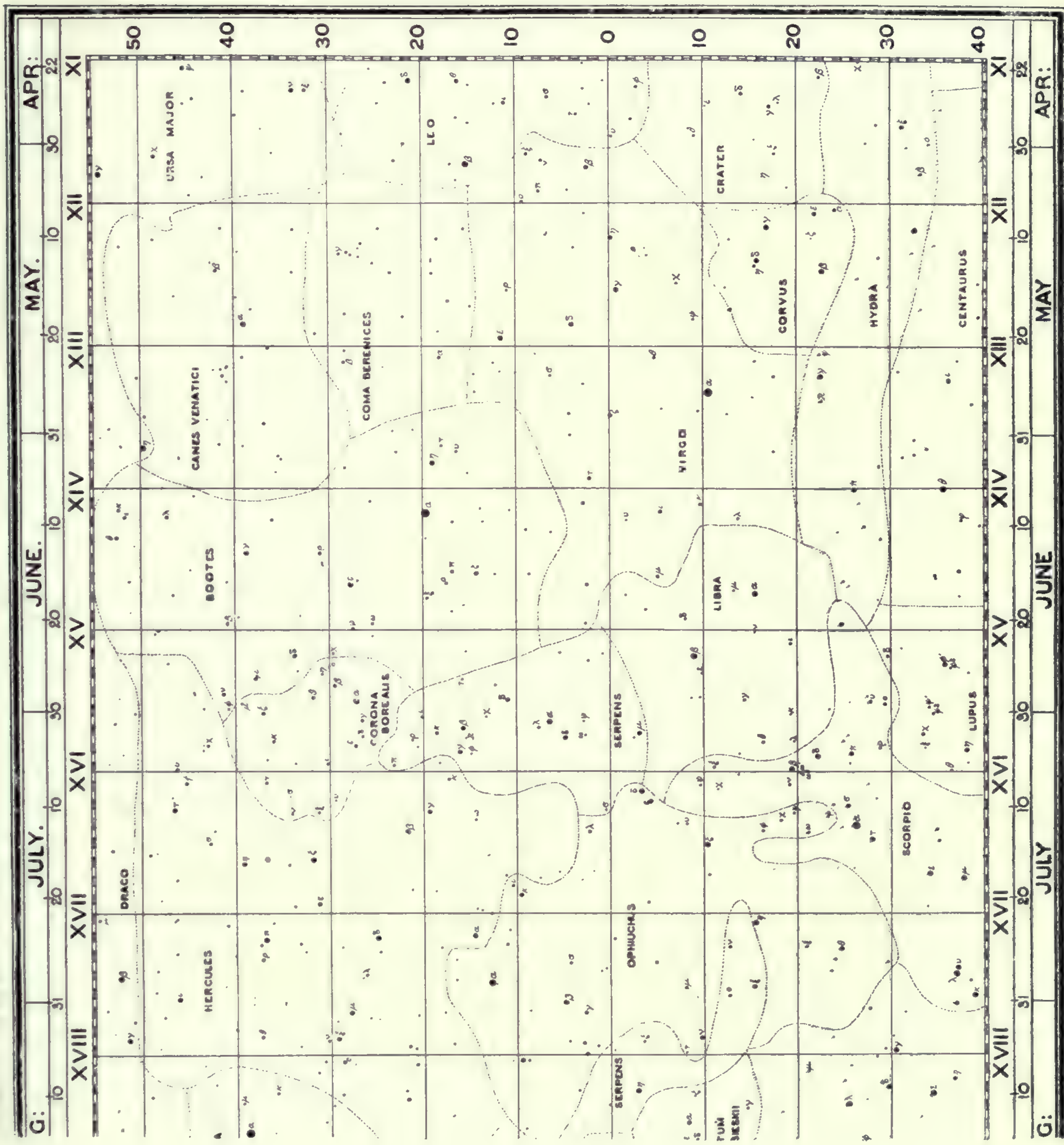

AURIGA
LYNX
GEMINI
CANIS MINOR
MONOCEROS
CANIS MAJOR
LEPUS
COLUMBA NOACHI
PUPPIS
CANCER
LEO
HYDRA
PYXIS NAUTICA
SEXTANS
ANTLIA PNEUMATICA
URSA MAJOR
LEO MINOR
CRATER
CORVUS
CANES VENATICI
COMA BERENICES
VIRGO
CENTAURUS
FEB:
MAR:
APR:
MAY
ARTHUR COTTAM, F.R.A.S. del.

KEY MAP No. 2


OCT.
NOV.
DEC.
JAN.
CASSIOPEIA
ANDROMEDA
PEGASUS
AQUARIUS
PISCES
SCULPTOR
TRIANGULUM
ARIES
CETUS
FORNAX CHEMICA
PERSEUS
TAURUS
CAMELOPARDUS
ERIDANUS
ORION
AURIGA
LEPUS
CAELUM SCULPTORIS
COLUMBA NOACHII
CANIS MAJOR


KEY MAP No. 3
NOV:
OCT:
SEPT:
AUG:
CASSIOPEIA
CYGNUS
LYRA
HERCU
ANDROMEDA
LACERTA
VULPECULA ET ANSER
SAGITTA
PEGASUS
DELPHINUS
PISCES
EQUULEUS
AQUILA ET ANTINOUS
SERPENS
CETUS
AQUARIUS
SCUTUM SOBIESKII
CAPRICORNUS
SAGITTARIUS
PISCIS AUSTRALIS
SCULPTOR
Epoch 1890.
ARTHUR COTTAM F.R.A.S. delt

KEY MAP No. 3


APR.
MAY.
JUNE.
JULY.
URSA MAJOR
LEO
CRATER
CORVUS
HYDRA
CENTAURUS
COMA BERENICES
CANES VENATICI
VIRGO
BOOTES
LIBRA
CORONA BOREALIS
SERPENS
LUPUS
SCORPIO
DRACO
HERCULES
OPHIUCHUS
SERPENS

Numbers alone :—

(*a*) Sloping figures—Flamsteed's Catalogue.

(*b*) Upright figures—F. G. W. Struve's Dorpat Catalogue of double and multiple stars.

(*c*) Upright figures underlined—S. W. Burnham's Catalogues of double stars.

Letters following numbers :—

OΣ or OΣ²—Otto Struve's Revised Pulkowa Catalogues of double and multiple stars.

h—Sir John Herschel's double stars.

Bris.—Brisbane's Catalogue of southern stars.

Lac.—Lacaille's Catalogue of southern stars.

B.A.C.—British Association Catalogue.

B. and B. Add.—Birmingham's Catalogue of red stars, and addenda thereto.

P., followed by Roman numeral—Piazzi's Palermo Catalogue, with hour of R.A. for 1800.

LL—Lalande's Catalogue.

S—Sir James South's Catalogue.

C—Chandler's Catalogue of variable stars.

Capitals without numbers—Variable stars.

Clusters and Nebulæ.

A number only—Messier's Catalogue of 103 bright nebulæ and clusters.

A number with a small number above it—Sir William Herschel's number, and the classes into which he divided these objects.

These classes are as under :—

I.	Bright nebulæ.	V.	Very large nebulæ.
II.	Faint nebulæ.	VI.	Very compressed and rich clusters of stars.
III.	Very faint nebulæ.	VII.	Compressed clusters of large and small stars.
IV.	" Planetary " nebulæ.	VIII.	Loose or scattered clusters of stars.

Letters following numbers :—

H.—Sir John Herschel's General Catalogue, 1864. Σ—F. G. W. Struve.

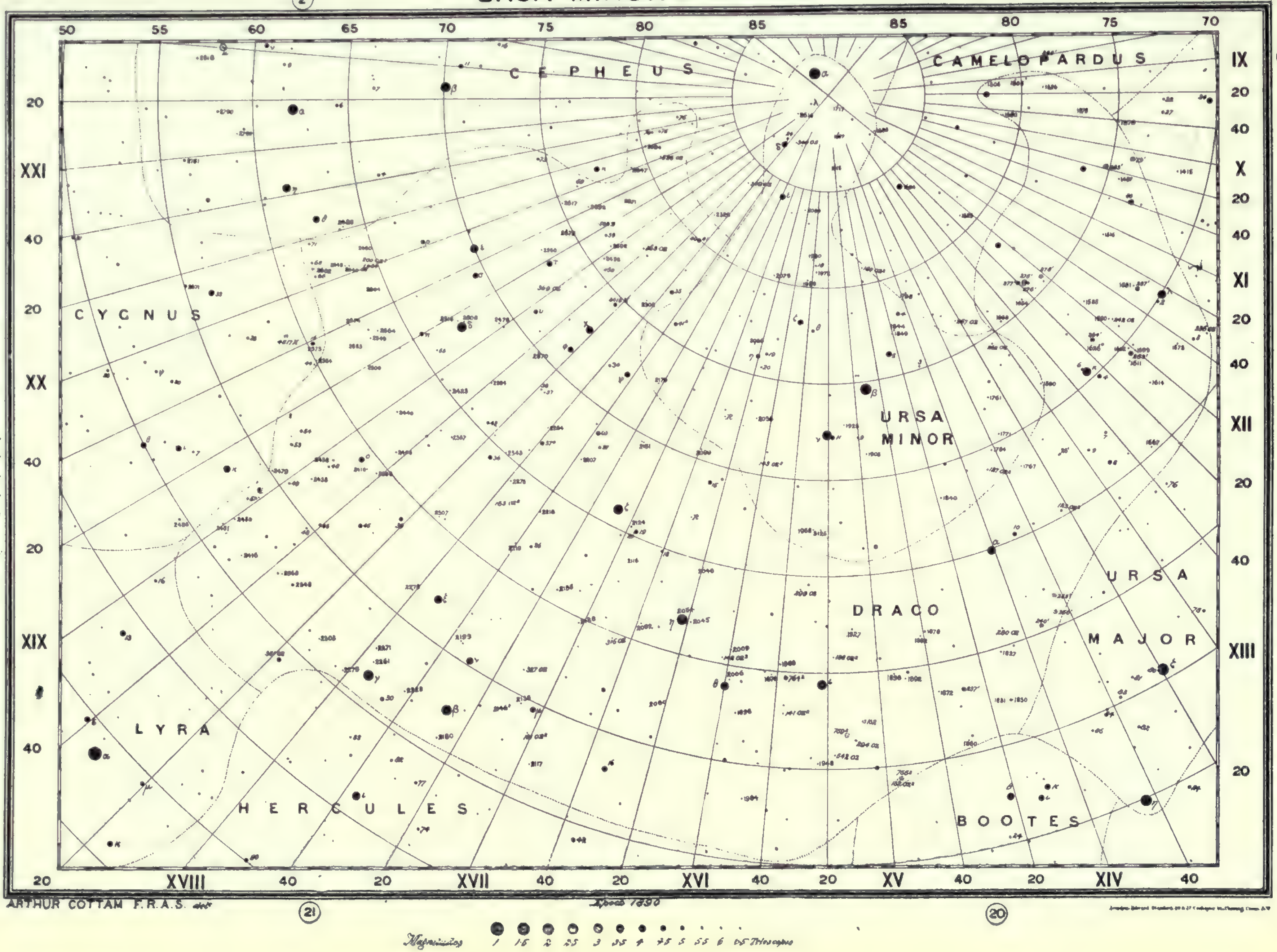
Dun.—Dunlop's Catalogue of southern nebulæ. Arg.—Argelander.

The beginner should early make himself familiar with the simple process of finding objects on the charts from a knowledge of their co-ordinates of Right Ascension and Declination, remembering that the procedure to be followed is precisely the same as that used for locating places on terrestrial maps. Right Ascension on the charts (corresponding to longitude on the Earth) is reckoned from west to east along the equator of the Heavens from the "first point of Aries." It is generally given in hours, minutes and seconds of sidereal time, and so marked at the margins of all modern maps. Occasionally, however, especially in telegrams announcing the discovery of comets and novæ, the old practice is followed of giving it in degrees, minutes and seconds of arc, referred to the equator as a great circle. In such cases it is only necessary to divide by 15 to arrive at the more common notation. Thus, for instance, R.A. 166° 17′ 45″ becomes 11*h*. 5*m*. 11*s*. Declination (corresponding to terrestrial latitude) is reckoned in degrees, minutes and seconds of arc along the meridians of Right Ascension in both directions from the equator. North Declination is often indicated by the sign +, and South Declination by the sign —. The Declination of the equator being zero, it follows that + 90° marks the North, and — 90° the South, Celestial Pole. In certain catalogues, and in telegraphic announcements of comets, &c., all possibility of confusing + with — (or N. with S.) is avoided by reckoning from the North Celestial Pole instead of from the equator. The resulting figures, from 0° to 180°, represent what is termed " North Polar Distance," or N.P.D. Thus the N.P.D. of a point on the equator is 90°, and N.P.D. 120° is the same as South Declination 30°, or Declination — 30°.

With a little care the position of a new or moving body that is invisible to the naked eye (such as Neptune, a comet or a minor planet) can be plotted from its co-ordinates with sufficient accuracy to enable it to be picked up readily with a low power, after noting the position it occupies with regard to

URSA MINOR & DRACO.

Nº I



ARTHUR COTTAM F.R.A.S. del.

neighbouring stars on the chart, as seen with the naked eye or with the finder. But, unless the object to be observed is conspicuous or of distinctive appearance, it will be necessary to take particular care in plotting its position, and also to make due allowance for the effects of precession. As already explained elsewhere, the continual slow change in the direction of the Earth's axis of rotation has the effect of altering the apparent Right Ascensions and Declinations of the stars by a small amount each year, though it does not affect their relative positions on the star-sphere. Consequently the co-ordinates marked on a star-chart are only strictly correct for one particular date, known as the Epoch of the map. Now, the Epoch of Mr. Cottam's charts is 1890, so that they are gradually becoming less and less strictly accurate as time goes on. However, the change is very slow and will not become serious for many years yet. In fact, it may be neglected for all ordinary purposes of the amateur observer. But for the sake of those who may desire at any time to plot the position of an object with considerable exactness, tables are here given of the necessary corrections to be applied to positions referred to epochs subsequent to that of 1890 in order that they may conform to the co-ordinates marked on the chart. The figures represent the amounts to be added or subtracted for every ten years' difference of epoch. Only one value is given for each hour of Right Ascension and each 10° of Declination, but, if desired, the corrections for intermediate positions can easily be estimated from the figures given.

Corrections for Precession in R.A. in Ten years.

(For reduction to an earlier Epoch.)

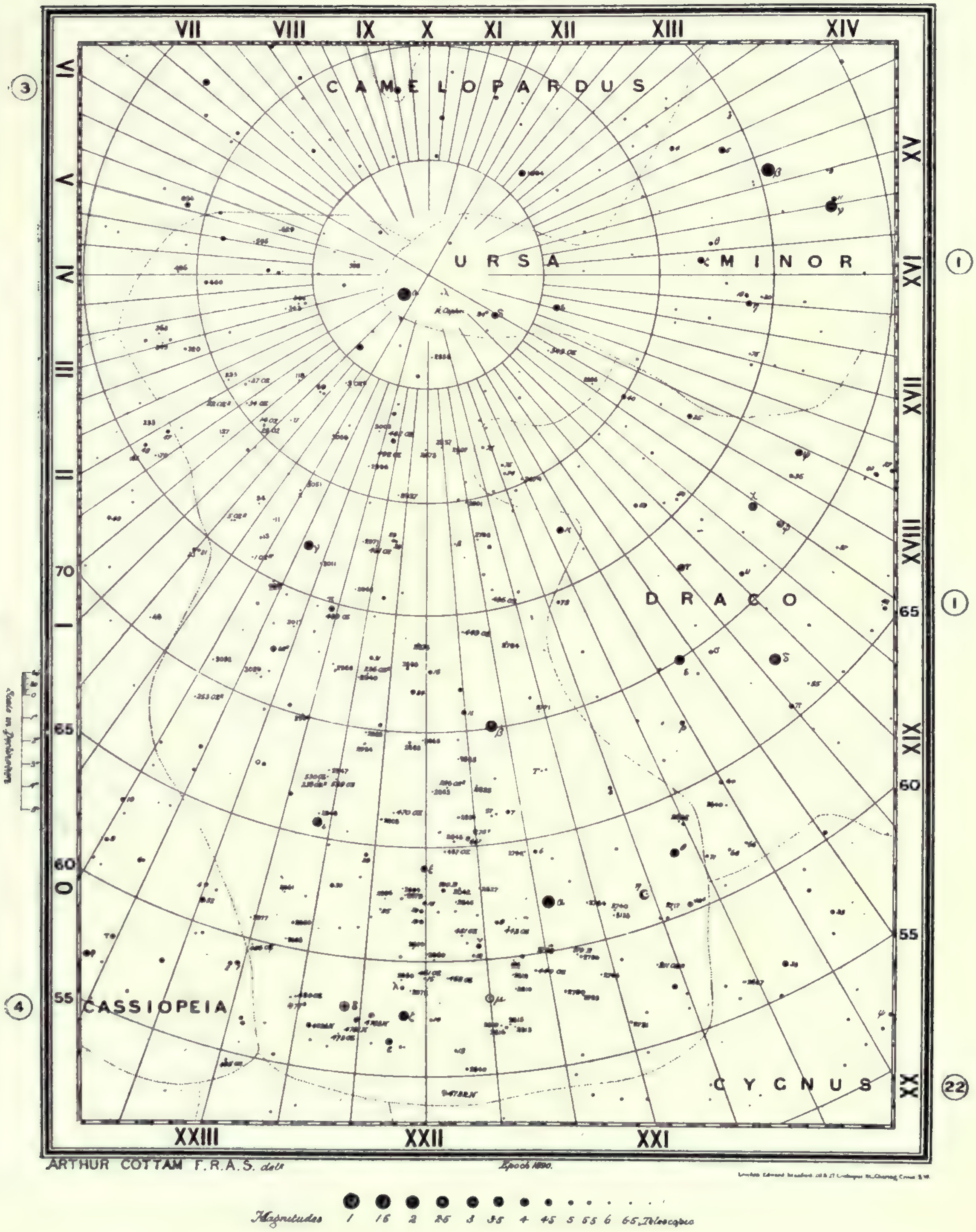
R.A. / Decl.	18*h*.	19*h*. 17*h*.	20*h*. 16*h*.	21*h*. 15*h*.	22*h*. 14*h*.	23*h*. 13*h*.	0*h*. 12*h*.	1*h*. 11*h*.	2*h*. 10*h*.	3*h*. 9*h*.	4*h*. 8*h*.	5*h*. 7*h*.	6*h*.
°	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.	*m*.
+80	+ ·75	+ ·71	+ ·58	+ ·38	+ ·12	− ·19	− ·51	− ·84	− 1·14	−1·41	−1·61	−1·73	−1·78
+70	+ ·10	+ ·08	+ ·02	− ·08	− ·21	− ·35	− ·51	− ·67	− ·82	− ·94	−1·04	−1·10	−1·12
+60	− ·13	− ·14	− ·18	− ·24	·32	− ·41	− ·51	− ·61	·71	− ·78	− ·85	− ·88	− ·90
+50	− ·25	− ·26	− ·28	− ·32	− ·38	− ·44	− ·51	·58	− ·64	− ·70	− ·74	− ·77	− ·78
+40	·33	·33	− ·35	− ·38	− ·42	− ·46	·51	− ·56	− ·61	− ·64	·67	·69	− ·70
+30	·38	·39	− ·40	− ·42	·45	− ·48	− ·51	− ·55	− ·58	− ·60	− ·62	− ·64	·64
+20	− ·43	− ·43	− ·44	− ·45	− ·47	− ·49	− ·51	− ·53	− ·55	− ·57	− ·58	− ·59	− ·59
+10	− ·47	− ·47	− ·48	− ·48	− ·49	− ·50	− ·51	− ·52	− ·53	− ·54	− ·55	− ·55	− ·55
0	− ·51	·51	− ·51	− ·51	− ·51	− ·51	− ·51	− ·51	− ·51	− ·51	− ·51	− ·51	− ·51
−10	− ·55	− ·55	− ·55	− ·54	− ·53	− ·52	− ·51	− ·50	− ·49	− ·48	− ·48	− ·47	− ·47
−20	− ·59	·59	− ·58	− ·57	·55	− ·53	− ·51	− ·49	− ·47	− ·45	− ·44	− ·43	− ·43
−30	− ·64	·64	− ·62	− ·60	·58	− ·55	− ·51	− ·48	− ·45	− ·42	− ·40	− ·39	− ·38
−40	− ·70	− ·69	− ·67	− ·64	·61	− ·56	·51	·46	− ·42	− ·38	− ·35	− ·33	− ·33
−50	− ·78	− ·77	− ·74	− ·70	− ·61	− ·58	− ·51	− ·44	− ·38	− ·32	− ·28	·26	− ·25
−60	− ·90	− ·88	− ·85	− ·78	− ·71	− ·61	·51	− ·41	− ·32	− ·24	− ·18	− ·14	− ·13
−70	−1·12	−1·10	−1·04	− ·94	− ·82	− ·67	− ·51	− ·35	− ·21	− ·08	+ ·02	+ ·08	+ ·10
−80	−1·78	−1·73	−1·61	−1·41	−1·14	− ·84	− ·51	− ·19	+ ·12	+ ·38	+ ·58	+ ·71	+ ·75

Corrections for Precession in Declination in Ten years.

(For reduction to an earlier Epoch.)

Right Ascension ...	0*h*.	1*h*. 23*h*.	2*h*. 22*h*.	3*h*. 21*h*.	4*h*. 20*h*.	5*h*. 19*h*.	6*h*. 18*h*.	7*h*. 17*h*.	8*h*. 16*h*.	9*h*. 15*h*.	10*h*. 14*h*.	11*h*. 13*h*.	12*h*.
Correction to Declination ...	′ −3·3	′ −3·2	′ −2·9	′ −2·4	′ −1·7	′ − ·9	′ 0	′ + ·9	′ +1·7	′ +2·4	′ +2·9	′ +3·2	′ +3·3

CEPHEUS No. 2

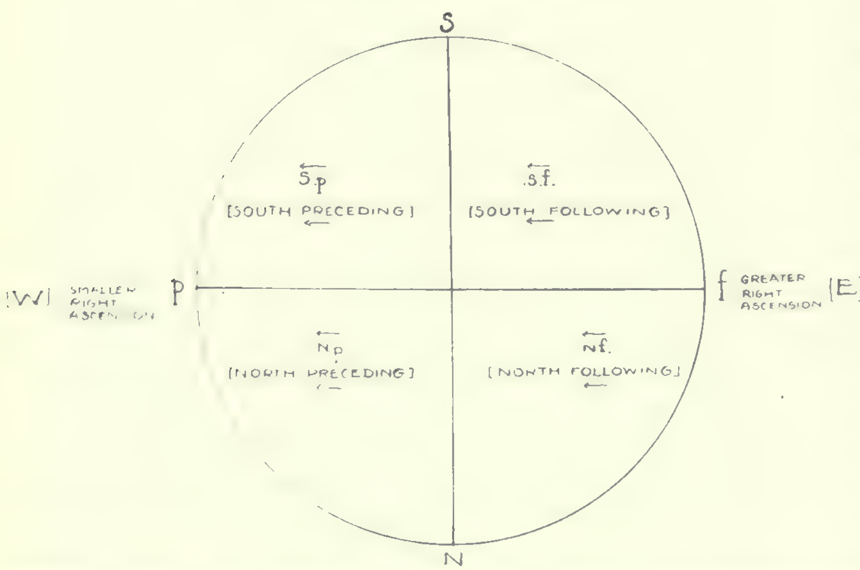

CAMELOPARDUS
URSA MINOR
DRACO
CASSIOPEIA
CYGNUS
VII VIII IX X XI XII XIII XIV
XV XVI XVII XVIII XIX XX
XXIII XXII XXI
VI V IV III II I 0
70 65 60 55
ARTHUR COTTAM F.R.A.S. delt
Epoch 1890.
Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 Telescopic

As an example of the use of these tables, let us imagine that a comet is discovered on 1925, April 6, the position for 1925·0 being announced as R.A. 16*h*. 0*m*. Decl. + 30°. In order to plot this position correctly among the stars on our charts we proceed as follows. From the first table the 10-yearly precession correction in R.A. for a body in this position is found to be − 0·40*m*. Now three and a half 10-year intervals have elapsed since 1890, so that the correction required is − 0·40*m*. × 3·5, or − 1·40*m*. As the sign is negative we subtract this from 16*h*. 0*m*., obtaining 15*h*. 58·6*m*. The Declination has now to be corrected. From the second table we find this correction to be + 1′·7 for each 10 years. Multiplying by 3·5 as before we get + 5′·95, or, say, + 6′·0. As the sign is positive we add this to + 30°. To mark the position of the comet on the chart we now adopt the corrected values 15*h*. 58·6*m*. + 30° 6′. It will be noted that the difference between these and the original figures corresponds to only a very small interval on the scale of our charts, and the comet, if at all bright, could probably have been found easily enough without taking it into account.

It is, perhaps, hardly necessary to point out that the tables just given will serve equally well in the case of positions given for epochs *prior* to 1890. All that is necessary is to reverse the signs. Thus, in the example imagined above, if the epoch had been 1855 instead of 1925, the corrections would have been + 1·40*m*. and − 6′·0 respectively.

The positions given against the nebulæ and clusters in the following list are for the epoch 1920·0, but, as the objects are all clearly marked on the charts, no correction need in practice be applied to the figures in order to find them, the difference between the positions at the two epochs being never more than a few hundredths of an inch on the paper.

THE TELESCOPIC FIELD.



In the accompanying chart are shown the conventional divisions of the field of view of an astronomical (*i.e.*, inverting) telescope, equatorially mounted. The arrows indicate the direction of a star's apparent motion through the field, caused by the rotation of the Earth. The four quadrants are named in relation to an object supposed to be in the centre of the field. The same relations hold for an altazimuth mounting, if careful note is taken of the direction of the star's apparent motion, but the N -S line will only be vertical to the altitude axis when the telescope is pointing towards the meridian ; whereas, in an equatorial, it remains constantly at right angles to the Declination axis.

CLUSTERS AND NEBULÆ.

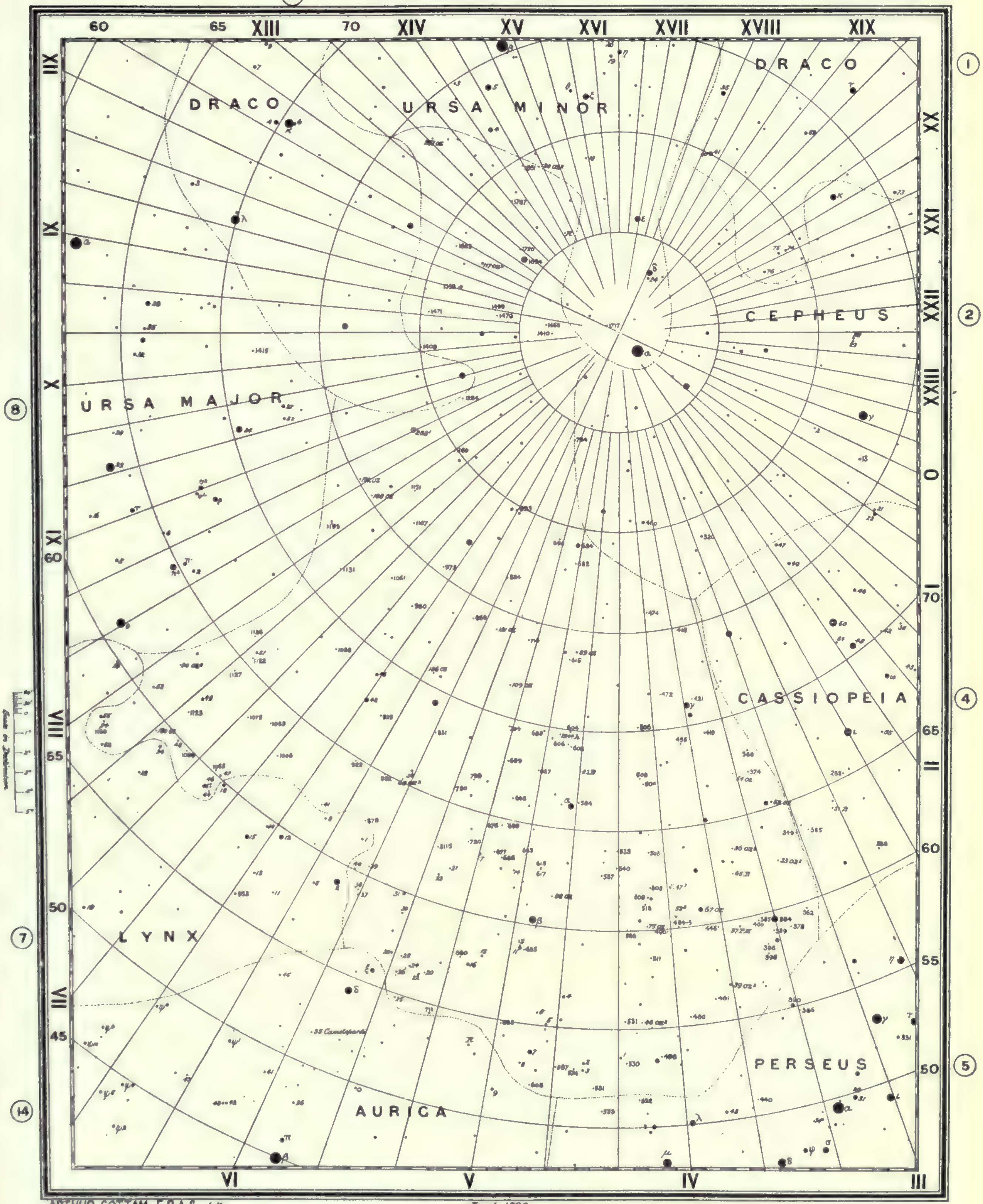
[Those more particularly striking are marked thus †.]

N.G.C. 205 (105H),$_1$ (18^5), *Andromedae, 0h.* 36·0*m*. + 41° 14′.

Faint elliptical nebula with diffuse edges and little central condensation. Even on the best photographs it appears almost structureless, and is chiefly of interest on account of its proximity to the great Andromeda Nebula. As it is situated only three-quarters of a degree

CAMELOPARDUS

No. 3



ARTHUR COTTAM F.R.A.S. delt

Epoch 1890.

Magnitudes 1 1·5 2 2·5 3 3·5 4 4·5 5 5·5 6 6·5 *Telescopic*

north preceding the latter it may even be included in the same field of view with a very low power. *See* page 55.

N.G.C. 221 (32), (117H), *Andromedae, 0h.* 38·4*m.* + 40° 26′.

Small round nebula markedly condensed in brightness towards its centre, in contrast with the last object described. It has much the same appearance as a globular cluster as seen in a telescope too small to resolve it into its component stars. However, it is probably truly nebular in character as very large instruments still fail to resolve it. It lies about 25 minutes of arc due south of the centre of the Great Nebula in Andromeda, and can therefore be seen in the same field of view with a low power. *See* page 55.

†*N.G.C.* 224 (31), (116H), *Andromedae, 0h.* 38·4*m.* + 40° 50′.

The "Great" Nebula in Andromeda. Clearly visible to the naked eye on transparent moonless nights. Owing to its great size and lack of definition the best general view is to be obtained with a very low power, or with the finder. It is then seen to be elliptical in outline and brighter towards the centre, but otherwise structureless, at any rate in small glasses. A high power, used on a fairly large telescope of not less than six inches aperture, will show a minute, almost stellar, nucleus ; and, if the night is very clear and dark, may show one or more of the dark parallel strips along the sides, which mark the spaces between the arms of the spiral. (*See* photographs on pages 55 and 561.) The true structure of the nebula cannot be made out visually, and was not revealed until the object was first successfully photographed by the late Dr. Isaac Roberts. The length of the entire nebula is over 2°, but of this ordinary telescopes only show about 40′ at all clearly. The nucleus has been suspected of variability, and might therefore repay a close study with high powers.

N.G.C. 598 (33), (352H), (17^5), *Trianguli, 1h.* 29·3*m.* + 30° 15′.

Very large faint nebula, best seen in the finder or with a very low power, and even then requiring a very dark clear night if its outer portions are to be seen. The central portions, which are the brightest, are easily made out, appearing as a round, ill-defined patch, slightly condensed in the middle. The nebula is actually a very fine example of a condensed spiral, whose arms, having lost their smooth curvature, are breaking up into myriads of small star-like fragments. (*See* photograph on page 579.)

†*N.G.C.* 869 *and* 884 (512 *and* 521H), (33^6 *and* 34^6), *Persei, 2h.* 15·1*m.* + 56° 47′.

Visible to the naked eye ; a small misty patch in the path of the Milky Way. Even a small telescope resolves this patch into two magnificent clusters of the loose or scattered type, of which they are among the finest examples in the Northern Hemisphere. A small finder gives quite a charming view of them, both being seen simultaneously, but they are best seen individually by employing a power that will just include one of them in the field at a time. There are at least five reddish stars in or between the two masses, and these are best seen with a reflector of fair aperture, say 8 to 10 inches. The photographs on pages 530 and 713 give some idea of the general appearance of the clusters as seen respectively in large and small telescopes.

N.G.C. 1039 (34), (584H), *Persei, 2h.* 36·9*m.* + 42° 26′.

Large loose cluster of bright stars, best seen with a low power. It contains a pretty double star, of separation about 1″·5, but the comparative faintness of the components makes it rather a difficult object in very small telescopes. The whole cluster is just visible to the naked eye on a dark night.

N.G.C. 1068 (77), (600H), *Ceti, 2h.* 38·6*m.* − 0° 21′.

Faint round nebula with strong central condensation. Easily found from its proximity to δ Ceti, which lies one degree to the west ("right" in the sky) and a little north of it. A ninth magnitude star will be seen close to the nebula in the telescope. As seen in large telescopes, and on photographs, the nebula is spiral in structure, and is remarkable as regards the character of its spectrum and its enormous velocity. It is illustrated on page 567.

† *The Pleiades. Position of central star* (*Alcyone*) *3h.* 42·7*m.* + 23° 52′.

The finest open star-cluster in the Heavens. Six or seven of the brighter stars are distinguishable with the unaided eye, and more have been seen by persons of acute vision. The whole group is best

W WNW NW NNW **Northern** N **Aspect** NNE NE ENE E

E ESE SE SSE **Southern** S **Aspect** SSW SW WSW W

THE STARS FOR APRIL.

"Our plate shows the aspect of the sky as seen, looking North and South, from Westminster Bridge; but the positions of the stars will be practically the same for any place in the latitude of Great Britain.

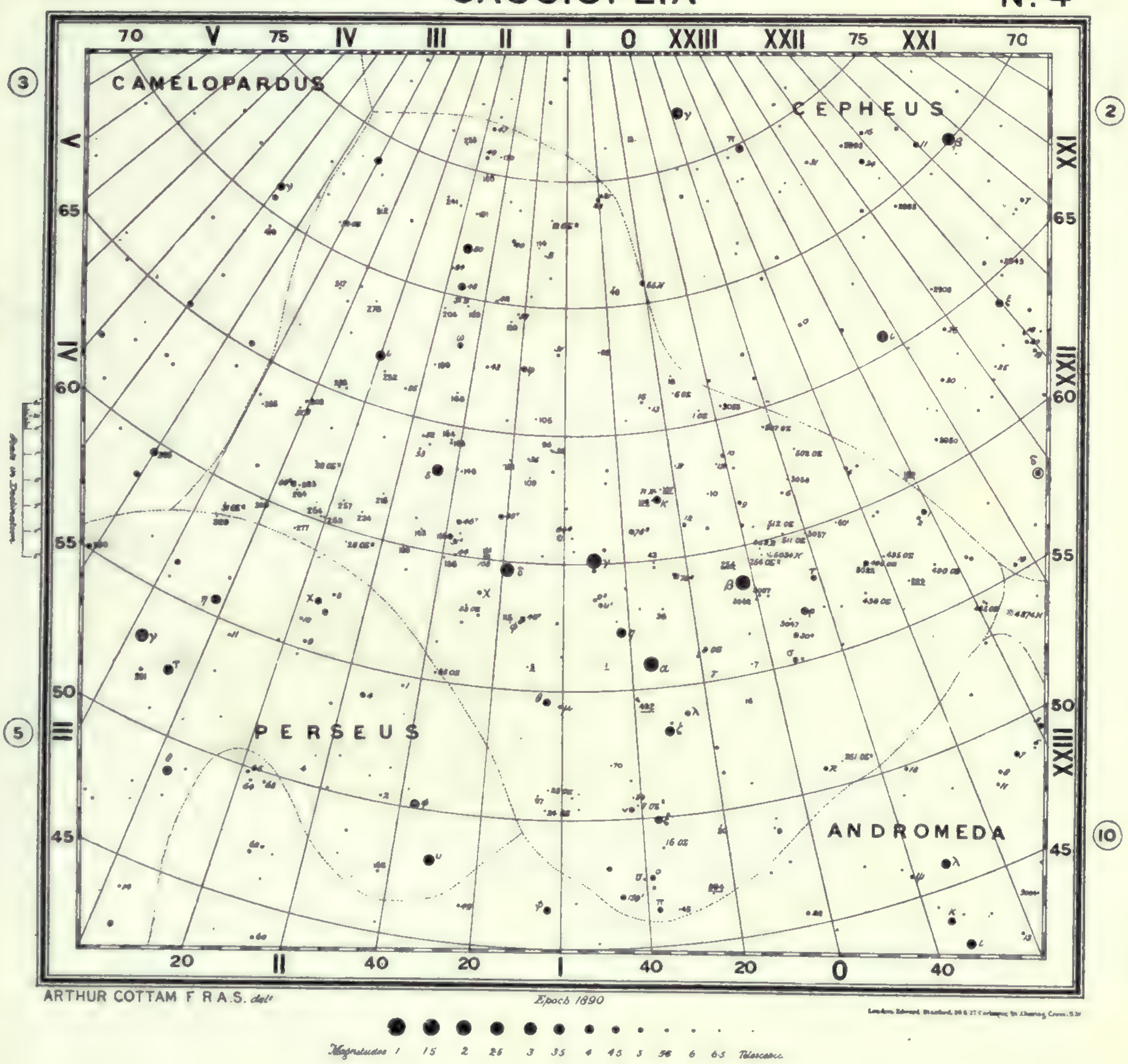
The constellations will appear in the positions shown on April 1 at about 11.30 p.m. (Greenwich Mean Time.)
" 8 " 11.0 p.m. " " "
" 15 " 10.30 p.m. " " "

seen with the finder or with binoculars, being too large to be included in one field with ordinary powers of the telescope. On a dark night traces of the nebulosity surrounding the chief stars (*see* pages 56 and 637) can be caught by averted vision in very small telescopes, but with large instruments it is not so obvious, except for a faint patch a few minutes of arc to the south of Merope. All the bright stars are of a very pure white colour, but near the centre of the group is a wide double whose components are seen in a large telescope (preferably a reflector) to be of an orange and pale green tint respectively. Alcyone, the brightest star in the cluster, has three companions, arranged in a triangle. A general view of the whole group, as it appears in a finder or in binoculars, will be found on page 712.

N.G.C. 1912 (38), (119H), *Aurigae, 5h.* 23·3*m.* + 35° 46′.

Fine loose cluster, whose component stars are arranged somewhat in the shape of a cross. Typical of the many open clusters to be found in this and other parts of the Milky Way. Such clusters are best seen with low powers.

CASSIOPEIA №4

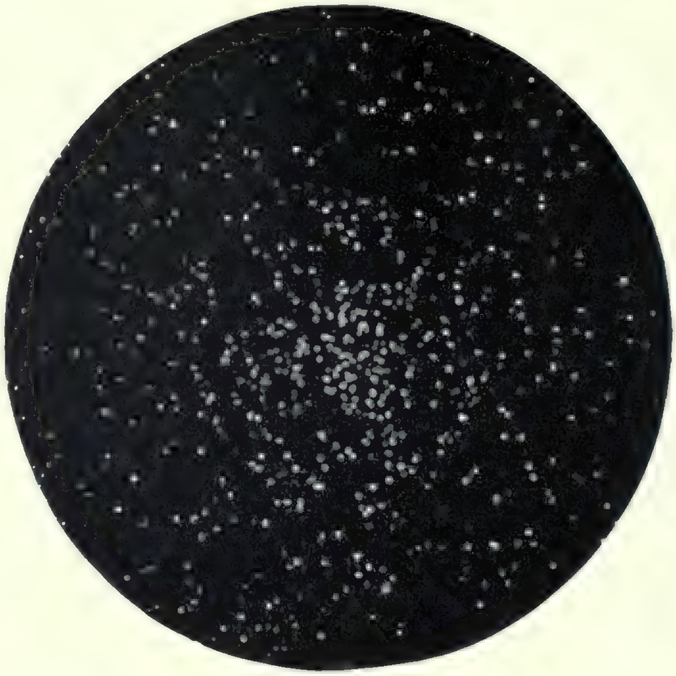


N.G.C. 1952 (1), (1157H), *Tauri,* 5*h*. 29·7*m*. + 21° 58′.

In small telescopes a dim oval mass of nebulosity, without condensation, about five minutes of arc in longest diameter, just visible in a good finder. With large apertures appears better defined and of somewhat irregular outline, rather the shape of a diamond on a playing-card. The delicate filaments extending outwards from its margin, discovered by the Earl of Rosse and shown on the latest photographs, are quite beyond the reach of small instruments. The nebula is readily picked up from its proximity to ζ Tauri. A fine picture of it appears on page 558.

N.G.C. 1960 (36), (1166H), *Aurigae,* 5*h*. 31·0*m*. + 34° 5′.

Loose cluster of stars of many degrees of brightness. Best picked up by sweeping in Right Ascension two degrees east of ϕ Aurigae.



N.G.C. 2099 (37), Aurigae.

†*N.G.C.* 1976 (42), (1179H), *Orionis,* 5*h*. 31·3*m*. − 5° 26′.

The Great Nebula in Orion. The only nebula, except that in Andromeda, that is clearly visible to the naked eye. It surrounds and involves a small group of stars near the centre of the "sword," and is thus very easily found. The entire nebula, with its faint outlying connections, covers a considerable area, but only the brighter central portions are well seen in small instruments. As seen with a low power, and preferably with averted vision, the nebula appears roughly fan-shaped, fading as it spreads out from the bright "Huyghenian" region, which is the name given to the central parts. This region, which is best seen with a fairly high power, is much better defined than the rest of the nebula, and exhibits a patchy or mottled structure in apertures over about 3 inches. In it is involved the multiple star θ, four of whose components are readily seen in very small glasses, and two more under very good conditions with apertures of 5 inches and over. Following θ is a striking dark wedge, apparently driven into the bright substance of the nebula, but believed by many to represent obscuring matter. It is best seen in large instruments, which bring out the contrast between it and the bright nebulosity in a very striking way. It is often referred to as the "Fish-mouth." A very good idea of the *visual* appearance of the nebula (which is of a delicate emerald green colour) is given by the illustration on page 553. On photographs the portions seen by the eye at the telescope are generally almost unrecognisable through over-exposure.

N.G.C. 2168 (35), Geminorum.

N.G.C. 2022 (1225H), (34[4]), *Orionis,* 5*h*. 37·7*m*. + 9° 2′.

Small planetary nebula, bluish in colour. Slightly elliptical, with long axis S*p*—N*f*. With large instruments it is seen to be somewhat less bright in the

centre. It is thus to be classed as an annular, or ring-nebula, but is smaller, fainter and more filled-in than the well-known Lyra nebula. (*See* later.) Seen with the finder or with a very low power it appears nearly stellar, owing to its small size, and may be missed in a casual sweep.

N.G.C. 2068 (78), (1267H), *Orionis*, 5*h*. 42·6*m*. + 0° 2′.

Small gaseous nebula, bright and fairly well defined along its northern edge but fading diffusely towards the south. Contains a wide double star, whose components are of the ninth or tenth magnitude. The nebula is easily found by sweeping eastwards from δ, the most westerly star of the "belt," with a low power.

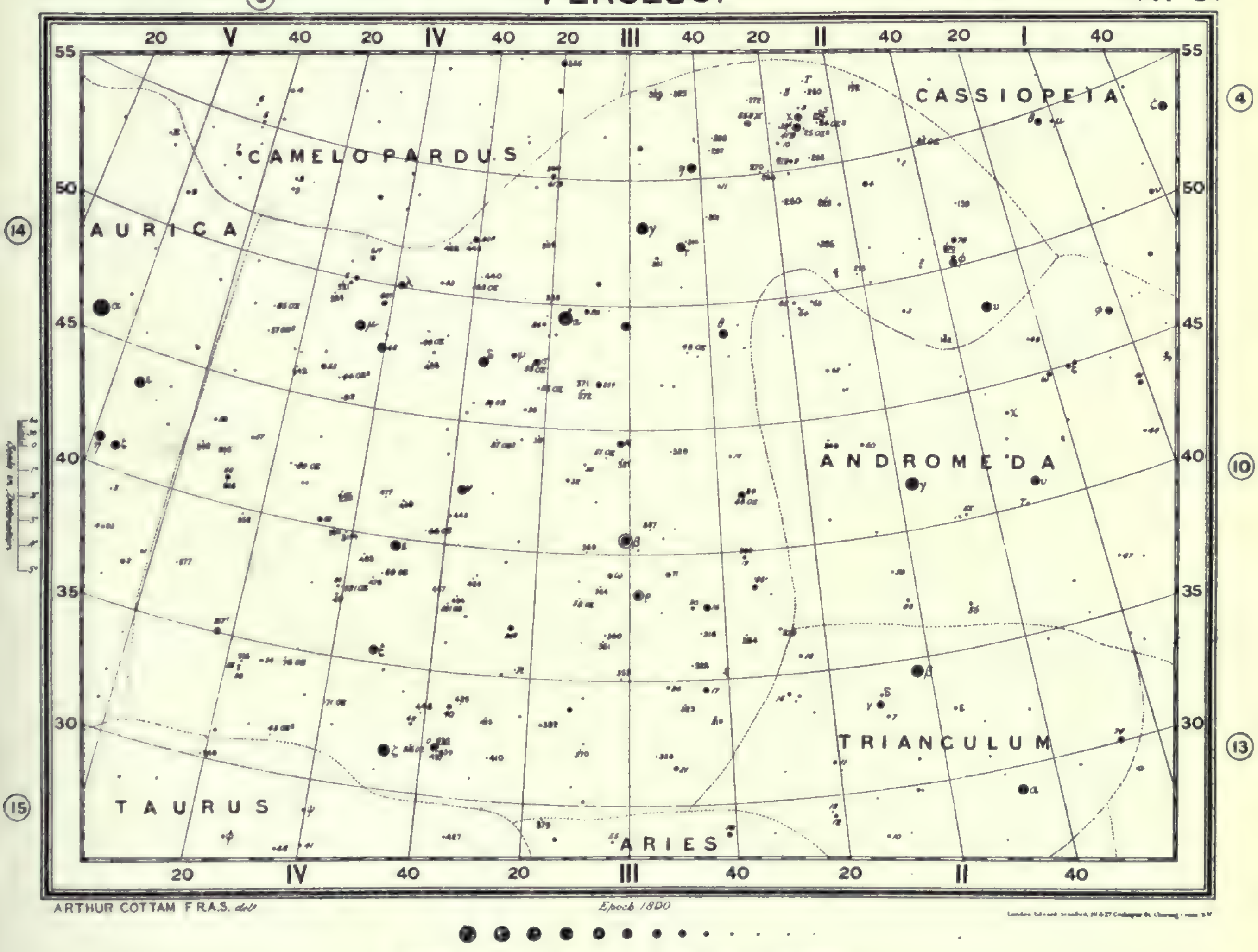
N.G.C. 2099 (37), (1295H), *Aurigae*, 5*h*. 47·1*m*. + 32° 32′.

A typical Galactic cluster of the open type. The individual stars are somewhat faint, but readily distinguishable even in the smallest instruments. Near the centre is a ruddy star of about the ninth magnitude. Clusters of this sort repay the use of averted vision, which brings their fainter components into view and thus adds to their apparent richness.

†*N.G.C.* 2168 (35), (1360H), *Geminorum*, 6*h*. 3·9*m*. + 24° 21′.

Fine open cluster containing stars of many degrees of brightness, the larger ones being easily seen

(3) PERSEUS. No. 5.



in small glasses. It lies very near the position at present occupied by the Sun at the Summer Solstice. Visible as a misty patch in the finder.

N.G.C. **2244 (1424H), (2[7]),** ***Monocerotis,*** **6*h*. 28·4*m*. + 4° 55′.**

Loose elongated cluster of a few bright stars, one of which is Flamsteed 12, of the sixth magnitude. The whole group just visible to the naked eye. It is well seen just above the centre of the photograph on page 539, where it is shown to be partly involved in the great diffuse nebula N.G.C. 2237. No trace of this nebulosity is visible in small instruments, and even large ones only give a faint and indefinite indication of it.

N.G.C. **2287 (41), (1454H),** ***Canis Majoris,*** **6*h*. 43·6*m*. − 20° 40′.**

Fine open star cluster, visible as a misty spot to the naked eye on dark nights. It lies about 4° south of Sirius, and is thus rather low for satisfactory observation in latitudes north of + 45°. The component stars are readily seen in a small telescope, and one of them, near the centre, is ruddy in colour, as in N.G.C. 2099 *supra*.

N.G.C. **2392 (1532H), (45[4]),** ***Geminorum,*** **7*h*. 24·4*m*. + 21° 5′.**

Small, bright, slightly elliptical planetary nebula, with its longer axis lying N—S. It has a bright stellar nucleus of about the eighth or ninth magnitude near its centre, the whole nebula, as seen in ordinary telescopes, being about twenty-five seconds of arc in diameter. Large apertures show traces of a dark ring closely surrounding the nucleus, and more marked on the following, or eastern side. With low powers, or on nights of poor transparency, little more than the nucleus is seen, and the latter has actually been recorded in catalogues as a star, its true nature being masked by the illumination of the field of the transit instrument used for the purpose. A photograph of the nebula, showing its bright central portions and the dark ring, appears on page 473.

N.G.C. **2437 (46), (1564H),** ***Argûs,*** **7*h*. 38·1*m*. − 14° 38′.**

Fine, roughly circular cluster of rather faint stars, about half a degree in diameter. Near its northern edge is N.G.C. 2438, a small planetary nebula of the annular type. It probably has no real connection with the cluster, which happens to lie in the same direction as seen from our region of space. Both objects are shown on the photograph on page 527, the nebula being the large white dot at the lower edge of the cluster.

N.G.C. **2440 (1567H), (64[4]),** ***Argûs,*** **7*h*. 38·3*m*. − 18° 1′.**

Small, bright planetary nebula of a bluish colour. Only about 12 seconds of arc in diameter, and therefore appearing almost stellar with low powers. Like other small planetaries, it is best seen under fairly high magnification, which increases the contrast with the black background of the sky, and serves to distinguish it at once from stars of the same brightness. Generally, such nebulæ show a fairly well-defined edge, but that of 2440 is somewhat diffuse. A ruddy star of the ninth or tenth magnitude, which follows it closely, may help to identify the nebula, which lies in a very rich region of the sky.

N.G.C. **2506 (1611H), (37[6]),** ***Argûs,*** **7*h*. 56·1*m*. − 10° 22′.**

Large mass of faint stars, situated in a fine region which well repays sweeping with a low power on a dark night. A photograph of the cluster appears on page 528.

†*N.G.C.* **2632 (44), (1681H),** ***Cancri,*** **8*h*. 35·5*m*. + 20° 16′.**

This large open cluster of bright stars, generally known as "Praesepe," is visible to the naked eye as a misty patch of light close to γ and δ Cancri. The smallest telescope, or even a pair of binoculars, is sufficient to resolve it into stars, and, owing to its size, it is really seen as satisfactorily in a finder as in a larger telescope. In instruments of moderate aperture some of the stars will be found to be yellow or orange in tint, and the prevailing tone of the majority is hardly so purely white as is the case with the chief stars of the Pleiades. Some of the stars are arranged prettily in pairs or triangles.

N.G.C. **2682 (67), (1712H),** ***Cancri,*** **8*h*. 26·9*m*. + 12° 6′.**

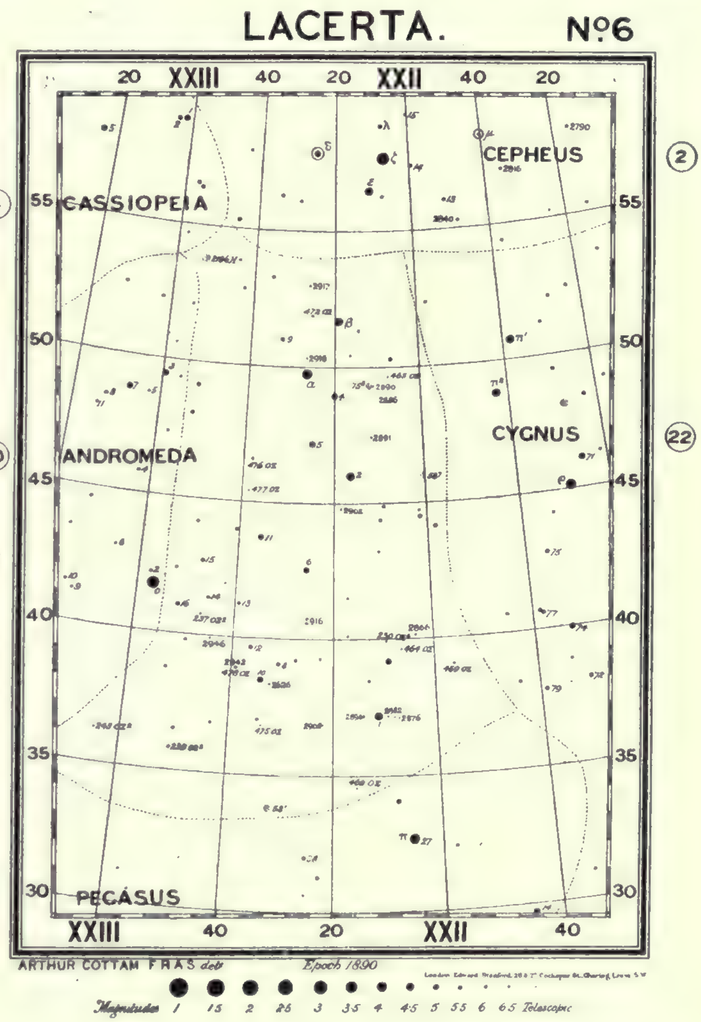
Fine open cluster of somewhat faint stars. Best seen on a dark night with a low power, and visible as a misty patch in the finder.

N.G.C. 3031 (81), (1949H), *Ursae Majoris*, 9*h.* 49·0*m.* + 69° 26′.

Bright elliptical nebula. Actually a fine spiral, but the arms are relatively faint, and only the bright central portion of the nebula is visible in small telescopes. This was one of the first nebulæ in which internal motions were detected and measured by a comparative study of photographs. *See* illustrations on pages 563 and 564.

N.G.C. 3034 (82), (1950H), *Ursae Majoris*, 9*h.* 49·2*m.* + 70° 4′.

Very much elongated nebula of the " ray " type ; really a spiral viewed very obliquely. Exhibits in large telescopes, two condensations, one on either side of the centre. Being only about 40 minutes of arc north following N.G.C. 3031 (*see* above), it is included with it in the same field, if the power used is very low.



N.G.C. 3242 (2102H), (27[4]), *Hydrae*, 10*h.* 20·9*m.* − 18° 14′.

Well-defined elliptical planetary nebula, about forty-five seconds of arc in diameter. It is of a delicate pale blue colour. With ordinary telescopes it appears fairly uniform in its light, but high powers on large instruments show a stellar nucleus and a faint circular border outside the brighter parts. With very low powers it is almost stellar in appearance, and has been observed as a star with meridian instruments. Two fine photographs of this object appear on page 557. They clearly show the faint outer border, and make the nucleus relatively much brighter than it is seen visually. This is the general rule with the nuclei of planetary nebulæ, which are rich in ultra-violet light, being Wolf-Rayet stars. (*See* Chapter XIV.)

N.G.C. 3379 (2203H), (17[1]), *Leonis*, 10*h.* 43·6*m.* + 13° 0′.

Faint round diffuse nebula with central condensation. A smaller and fainter one follows it. These two objects are typical of the many similar nebulæ in the vicinity, where stars are relatively scarce. All the larger ones appear as spirals on the photographic plate, but are not so seen visually with ordinary apertures.

N.G.C. 3587 (97), (2343H), *Ursae Majoris*, 11*h.* 10·0*m.* + 55° 27′.

Faint circular nebula, about 2½ minutes in diameter. It is one of the largest of the " planetary " nebulæ, but is also one of the faintest, and is only well seen in a dark clear sky and with a large aperture. With small telescopes it appears uniformly bright, but large instruments show two dusky patches or vacuities, one on either side of the centre, which is marked by a stellar nucleus conspicuous on photographs. Easily found from its proximity to a small star near β Ursae Majoris, one of the " pointers " of the Plough. A photograph of the nebula will be found on page 135.

N.G.C. 4254 (99), (2838H), *Virginis*, 12*h*. 14·8*m*. + 14° 52′.

Bright round nebula with central condensation. On photographs, and in very large telescopes, is seen to be a spiral, but only the bright central portions are visible in small telescopes. Lies near the boundary of Coma Berenices, and is included by some authorities in this constellation. A photograph of the nebula appears on page 576.

N.G.C. 4501 (88), (3049H), *Virginis*, 12*h*. 28·0*m*. + 14° 52′.

Bright, very much elongated nebula with central condensation. Actually a fore-shortened spiral. Easily found by sweeping eastwards from the nebula last described. Telescopes of considerable aperture show a very great number of very similar nebulæ in this region, and it is not always an easy matter to be sure of the identity of each one. Several are sometimes to be seen in the same field if a low power is used. The one here described is illustrated on page 576. Like the previous object, it is sometimes included within the boundaries of Coma Berenices.

Photo by] [*W. H. Steavenson.*

N.G.C. 2632, (44) Cancri, as seen in binoculars, or with a finder. (*See* page 892.)

N.G.C. 4565 (3106H), (24[5]), *Comae Berenices*, 12*h*. 32·4*m*. + 26° 26′.

Very elongated nebula of the "ray" type. Much thicker and brighter near its centre, where it is strongly condensed. Closely following the nucleus is a smaller and fainter ray, parallel with the main one, and separated from it by a narrow dark lane. The nebula is actually a spiral seen almost exactly edgewise, the dark lane being an effect of absorption by the outlying parts on the side nearest to us. A photograph of this interesting object will be found on page 575.

N.G.C. 4826 (64), (3321H), *Comae Berenices*, 12*h*. 52·8*m*. + 22° 7′.

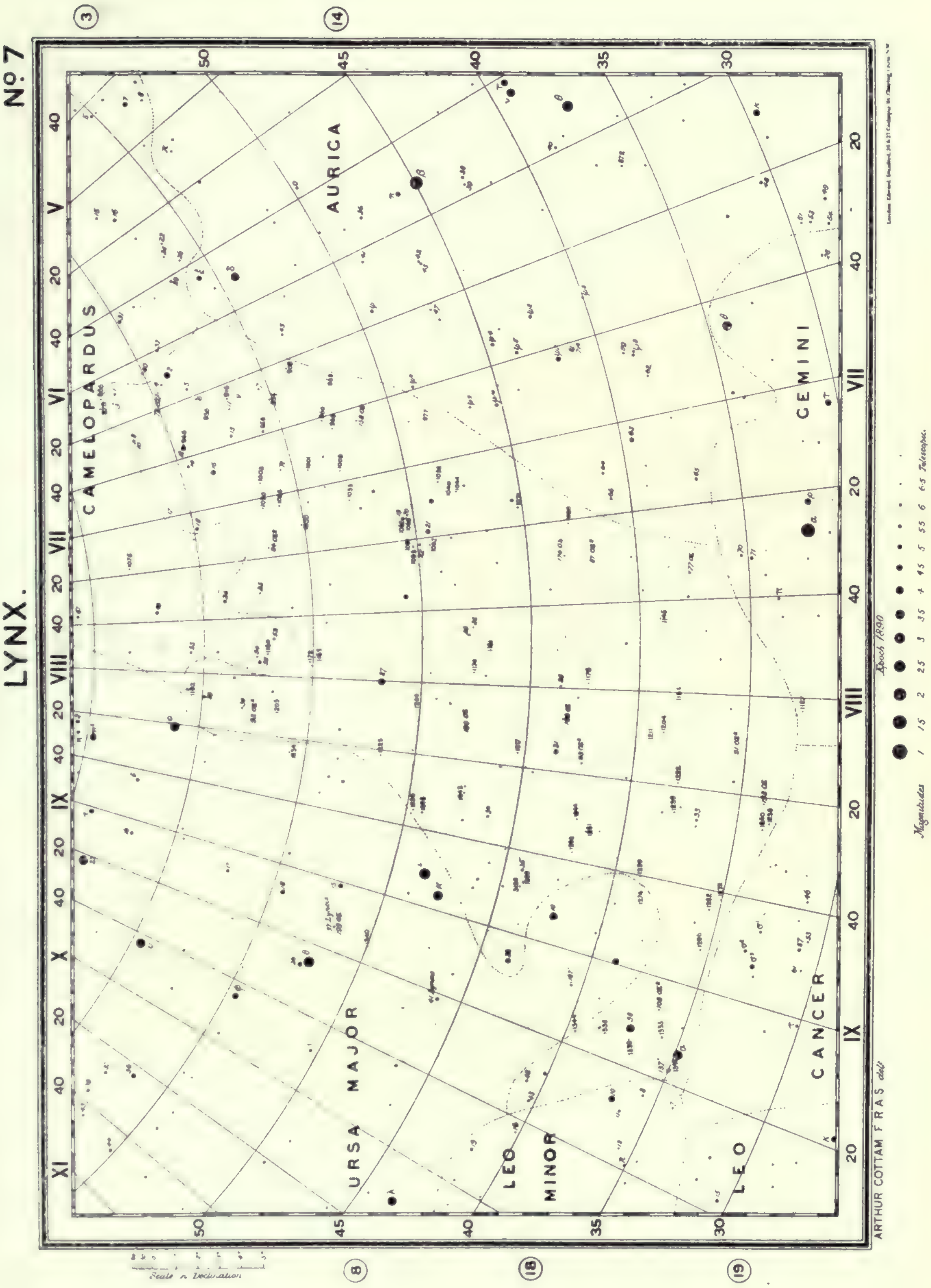
Ill-defined elliptical nebula with bright centre, near to which a dark streak (probably absorbing matter) is visible with large apertures. The nebula is a fore-shortened spiral of the uncondensed type, and is illustrated on page 569.

N.G.C. 5055 (63), (3474H), *Canum Venaticorum*, 13*h*. 12·2*m*. + 42° 27′.

Bright elliptical nebula with central condensation, closely following a star of about the eighth magnitude. The photograph of it, which will be found on page 581, shows it to be a fore-shortened spiral of complex form.

N.G.C. 5194/5 (51), (3572/4), (186[1]), *Canum Venaticorum*, 13*h*. 26·5*m*. + 47° 36′.

Two round condensed nebulae, of very similar appearance in small glasses; quite easily picked up with a good finder on a dark night by alignment with η Ursae Majoris, the star at the end of the Bear's tail. In large telescopes the more southerly of the two is seen to be surrounded by a faint halo, which takes on a spiral aspect in apertures approaching 12 inches. This was the first spiral nebula to be detected as such by the Earl of Rosse. A glimpse of some of the stellar condensations along the arms can be obtained by averted vision in instruments of about 10 inches aperture or over. A fine photograph of this famous object appears on page 572. Visually it is somewhat disappointing in ordinary telescopes.


Nº 7
LYNX.
CAMELOPARDUS
AURICA
GEMINI
URSA MAJOR
LEO MINOR
LEO
CANCER
ARTHUR COTTAM F R A S delt
Epoch 1890
Magnitudes
Telescopic
Scale in Declination

†*N.G.C.* 5272 (3), (3636H), ***Canum Venaticorum***, **13*h*. 38·5*m*. + 28° 47′.**

Just visible to the naked eye on a dark night. It is not near to any bright stars, but can be readily picked up in the finder by sweeping towards Arcturus from a point about half-way between that star and Cor Caroli (α Canum Venaticorum). In telescopes below three inches aperture it appears as a bright circular nebula, somewhat condensed towards its centre. In a four-inch telescope it appears spangled with bright points, which are separately seen towards the edges of the mass, but are crowded into a confused mass in the central parts. A six-inch aperture, used in conjunction with a high power, will resolve the object throughout into separate stars, though larger glasses are needed to give a really satisfactory view. It is a typical example of a globular cluster, and is one of the finest of its kind in the northern hemisphere. A photograph of it is given on page 536.

N.G.C. 5904 (5), (4083H), ***Librae***, **15*h*. 14·4*m*. + 2° 22′.**

A fine globular cluster, but not equal in size or brightness to the object just described. Easily found from its proximity to the fifth magnitude star 5 Serpentis. Like most globulars it appears as a conspicuous bright spot in the finder.

N.G.C. 6093 (80), (4173H), ***Scorpii***, **16*h*. 12·3*m*. − 22° 47′.**

A globular cluster. It is a fine object in a large telescope, but the individual stars are somewhat faint and quite invisible as separate objects with small apertures. With a two- or three-inch glass the cluster looks like a round nebula with bright condensed centre. In a pretty neighbourhood.

N.G.C. 6121 (4), (4183H), ***Scorpii***, **16*h*. 18·7*m*. − 26° 20′.**

Faint cloud of small stars, appearing like a nebula in the finder, but readily resolved with quite a small aperture. A four-inch telescope shows it splendidly.

†*N.G.C.* 6205 (13), (4230H), ***Herculis***, **16*h*. 38·8*m*. + 36° 36′.**

Bright and large globular cluster, generally considered the finest of its class in the northern hemisphere. Just visible to the naked eye, a third of the way from η to ζ Herculis, and quite conspicuous in the finder. Can be resolved in parts by averted vision with a three-inch telescope, but an aperture of about six inches is required to give a satisfactory view of the more condensed central parts. Globular, unlike open, clusters are much better seen with fairly high powers, since these have the effect of darkening the field and separating out the closely crowded component stars. The "Great Hercules Cluster," as it is generally called, is prettily placed with regard to two small neighbouring stars, and a large field includes a small faint nebula about forty minutes of arc to the north-east, that is north-following. A very fine photograph of the great cluster appears on page 533.

†*N.G.C.* 6210 (4234H), (Σ 5), ***Herculis***, **16*h*. 41·6*m*. + 47° 40′.**

Very bright small planetary nebula. In the finder and with low powers it is scarcely distinguishable from a star of about the eighth magnitude (for which it has more than once been mistaken by meridian observers). With high powers it appears as a bluish-green disc about eight seconds of arc in diameter. Owing to its brightness it is a very suitable object for examination with a small spectroscope, which should have its slit or cylindrical lens removed for the purpose. The single bright image that will then be seen (or perhaps two more in a large glass) contrasts strikingly with the familiar linear spectrum of a star, as observed with the same apparatus.

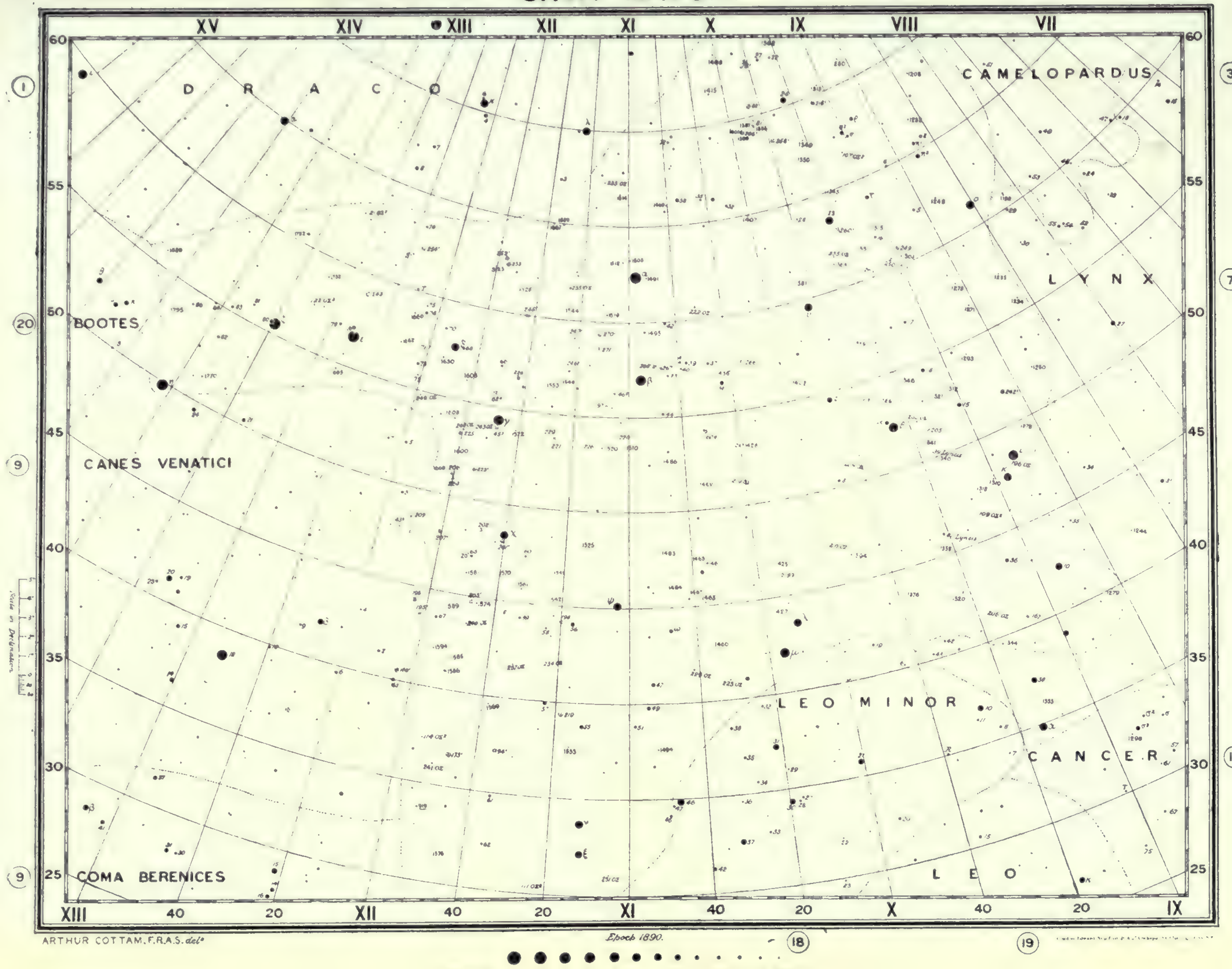
N.G.C. 6218 (12), (4238H), ***Ophiuchi***, **16*h*. 43·1*m*. − 1° 48′.**

In very small telescopes a circular nebulosity with bright centre and diffuse edges. In larger instruments it is a very interesting object, being intermediate in type between the globular and loose clusters, the stars having a distinctly spherical distribution without the marked degree of agglomeration observable in such objects as the great Hercules cluster. The object is illustrated by a photograph on page 534.

†*N.G.C.* 6341 (92) (4294H), ***Herculis***, **17*h*. 14·7*m*. + 43° 14′.**

A fine globular cluster resembling its near neighbour M 13, already described, but smaller and more markedly condensed at its centre. For the latter reason it is not quite so easy to resolve it completely, but when this is done, with a large instrument, there is little to choose between the two objects, though for some reason it has been the custom to give a disproportionate prominence to M 13 in text-book descriptions of clusters.

URSA MAJOR. №8.



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†*N.G.C.* **6405 (6), (4318H),** ***Sagittarii,*** **17*h*. 34·9*m*. – 32° 9·5′.**

A most beautiful open cluster of stars of the galactic type, but rather too far south for satisfactory observation in latitudes north of + 45°. It is somewhat rectangular in shape, with a central rib of stars, and resembles a butterfly with open wings.

N.G.C. **6514 (20), (4355H), (41⁴),** ***Sagittarii,*** **17*h*. 57·5*m*. – 23° 2′.**

The "Trifid" nebula. Not very striking in small instruments, which show an ill-defined nebulous glow involving a few faint stars. Large apertures show the three irregular dark rifts which give the nebula its name, but these come out much more strikingly on photographs. The nebula is illustrated on page 543. It is in a fine region, well worth sweeping through with a low power on a dark night.

N.G.C. **6523 (8), (4361H),** ***Sagittarii,*** **17*h*. 58·8*m*. – 24° 23′.**

Visible to the naked eye and conspicuous as a misty patch in the finder. A small telescope shows a loose and irregular cluster of small stars, involved in ill-defined nebulosity, which latter comes out more clearly to averted vision, or by slightly moving the tube of the instrument from side to side. A photograph of this object will be found on page 526, but the reader may here be warned not to expect to see visually, in this and similar objects, a tenth of the detail brought out so clearly in such pictures.

N.G.C. **6543 (4373H), (37⁴),** ***Draconis,*** **17*h*. 58·6*m*. + 66° 38′.**

Bluish, nearly circular planetary nebula, about a third of a minute of arc in diameter. With large apertures a minute stellar nucleus is visible. This nebula is famous as having been the first to reveal its gaseous nature to the spectroscope of Huggins. Intrinsically it is not nearly so bright as Σ 5 Herculis (or Σ 6 below), but is considerably more luminous than M 97 Ursae Majoris, the so-called "Owl" nebula. It lies very close to the North Pole of the Ecliptic.

†*N.G.C.* **6572 (4390H), (Σ 6),** ***Ophiuchi,*** **18*h*. 8·7*m*. + 6° 50′.**

A minute bluish planetary nebula, very much like Σ 5 Herculis, but even smaller and brighter. Intrinsically it is quite one of the most luminous nebulæ in the whole heavens—and for this reason alone is well worth looking up. It is only about six seconds of arc in diameter, and with a very low power would certainly be passed over as a star of the eighth magnitude. It forms the preceding end of a long isosceles triangle, the northern star of the two forming the base being the brighter.

N.G.C. **6618 (17), (4403H),** ***Scuti,*** **18*h*. 16·3*m*. – 16° 13′.**

Curious arch of nebulosity, best seen with low powers. Just visible in the finder. At one end of the arch is a straight extension at an acute angle. The nebula has been likened to a horse-shoe. Many fine clusters and groups of stars are to be seen by sweeping in this rich region of the heavens, which contains the brightest portion of the Milky Way visible in mid-latitudes of the northern hemisphere.

†*N.G.C.* **6656 (22), (4424H),** ***Sagittarii,*** **18*h*. 31·5*m*. – 24° 3′.**

Fine globular cluster, the largest visible north of latitude 42° N. Owing to the brightness of its component stars it is more readily resolvable with moderate instruments than most objects of its type. If it were so favourably placed for northern observers as the great Hercules cluster, it would probably receive at least as much attention and admiration as that object.

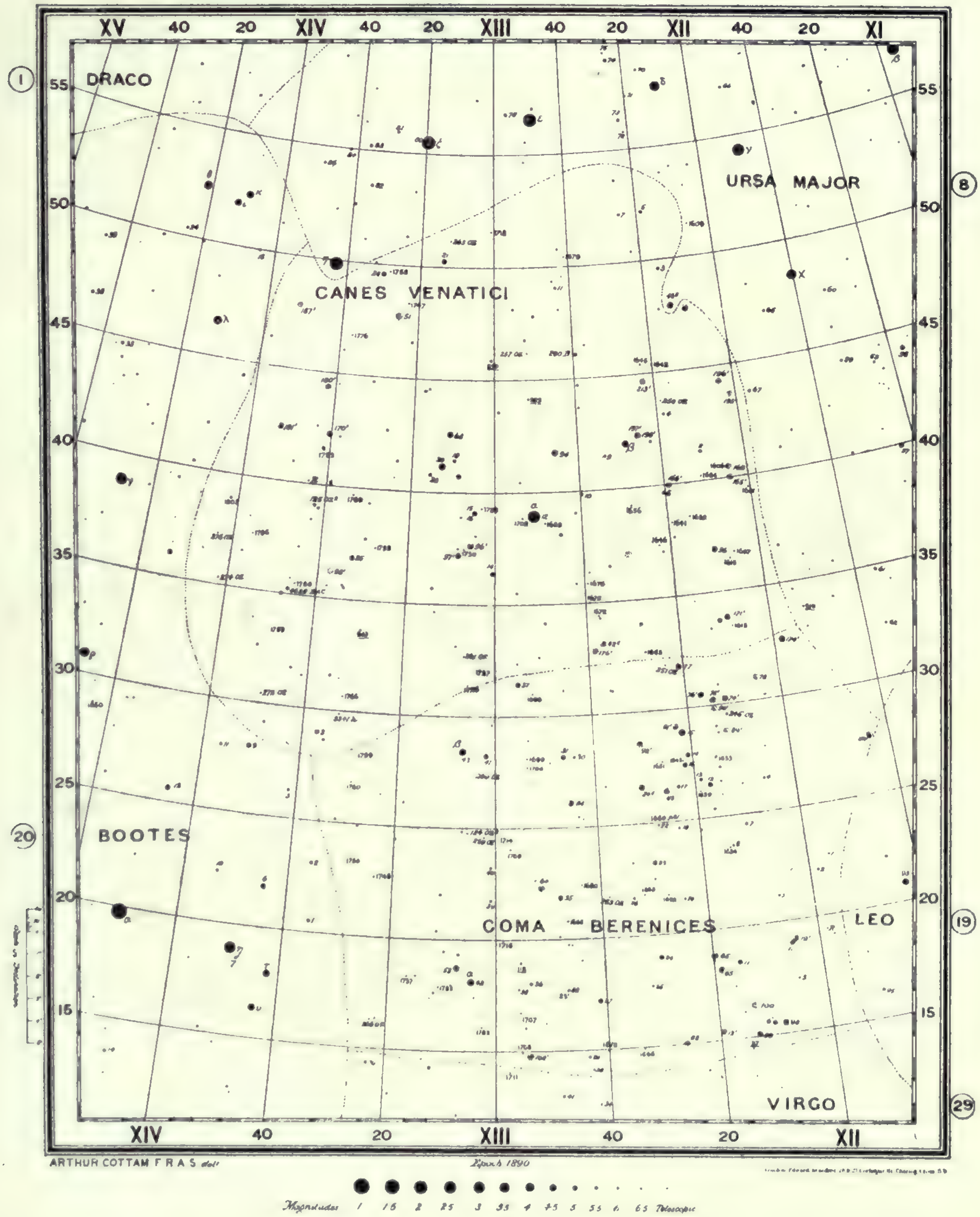
†*N.G.C.* **6705 (11), (4437H),** ***Scuti,*** **18*h*. 46·6*m*. – 6° 22′.**

Beautiful compact cluster of stars, situated on the northern edge of the smaller star-cloud of Sagittarius, and visible as a misty spot in the finder. It is readily resolved in a two- or three-inch telescope, where it appears wedge-shaped, with a brighter star at the apex. The whole formation of the cluster, as seen thus, has been compared to that assumed by wild ducks in flight. M 11 is in type very similar to M 12, already described. That is to say, it is more compact than the typical loose cluster, but less so than the globular.

†*N.G.C.* **6720 (57), (4447H),** ***Lyrae,*** **18*h*. 51·1*m*. + 32° 56′.**

The well known ring nebula in Lyra, the finest example of the annular planetary nebulæ. Visible

CANES VENATICI & COMA BERENICES. No. 9.



in quite a small telescope. With low powers it appears as a well-defined elliptical patch of faint nebulosity, measuring about sixty by eighty seconds of arc. A three-inch telescope, with a fairly high power, shows a dusky centre, turning the patch into a ring. With apertures over four inches this central region can be seen to be not completely dark, and every increase of aperture adds to this " filling-in " of the ring with nebulous matter. A six-inch glass will show that the ring is fainter at the ends of its long axis than at the sides. The central star, or nucleus, so conspicuous on photographs of the nebula, is a relatively faint visual object, being scarcely discernible with apertures below about fifteen inches. Its stellar magnitude is about 15·5. A small star of about the thirteenth magnitude immediately follows the nebula, and is readily seen with apertures over four inches. A photograph of the nebula appears on page 127.

N.G.C. **6779 (56), (4485H),** ***Lyrae,*** **19*h*. 13·5*m*. + 30° 2′.**

Small faint cluster of the semi-globular type, easily found nearly half-way along a straight line drawn from β Cygni to γ Lyrae. It is not very closely packed, but the faintness of the individual stars makes them difficult to see separately with apertures below about four inches. The cluster is, however, a fine object as seen with a very large telescope.

N.G.C. **6838 (71), (4520H),** ***Sagittae,*** **19*h*. 50·2*m*. + 18° 34′.**

Somewhat similar in type to the object just described, but larger and brighter. The brighter of the individual stars can be seen with a three-inch telescope, but larger apertures greatly augment the number, and the cluster is quite a striking object in a six- or eight-inch glass. It is situated in the Milky Way, where the sweeping is fine.

†*N.G.C.* **6853 (27), (4532H),** ***Vulpeculae,*** **19*h*. 56·1*m*. + 22° 30′.**

The " Dumb-Bell " nebula. This is, as regards its apparent diameter, quite the largest of the planetaries. It is clearly visible in a small finder on a dark night, and is an interesting object in any aperture over two inches. On two opposite sides it exhibits a well-defined curved outline, which is, however, indented and diffuse in the intervening sections. These indentations, corresponding to the " grip " of the dumb-bell, are less obvious with large apertures, which show faint extensions of nebulosity stretching outwards from each, and increasing the diameter of the nebula to about nine minutes of arc in this direction. In small instruments the nebula appears broadest at right angles to this diameter, the distance from edge to edge being five minutes of arc. With telescopes over about five inches in aperture a few faint stars can just be seen projected on the surface of the nebula, but they probably have no connection with it. A photograph of this interesting object appears on page 554.

†*N.G.C.* **7009 (4628H), (1^4),** ***Aquarii,*** **20*h*. 59·8*m*. − 11° 41′.**

Small bluish planetary nebula, elliptical in outline, measuring about twenty-five by eighteen seconds of arc. Appears practically stellar with low powers and has been catalogued as a star on at least one occasion. With high powers a darker central region is seen, and the object appears very much like the ring nebula in Lyra, except that it is smaller, brighter, and less dark in the middle. Large apertures show faint extensions of the ellipse on either side in the direction of the major axis, which lies N*f*—S*p*. The Earl of Rosse saw these extensions as thin filaments of nebulosity, and noted that this gave the nebula an outline similar to that of the planet Saturn. The nebula is consequently referred to as the " Saturn nebula " in many text-books. Small instruments do not bring out any such resemblance.

N.G.C. **7089 (2), (4678H),** ***Aquarii,*** **21*h*. 29·3*m*. − 1° 12′.**

Fine large globular cluster containing a very great number of stars. In small apertures, however, it appears simply as a circular nebula, its components being too faint to be separately seen. In large instruments it is a magnificent object.

N.G.C. **7078 (15), (4670H),** ***Pegasi,*** **21*h*. 26·1*m*. + 11° 49′.**

Fine globular cluster of moderate size, visible as a blurred star in the finder. It is strikingly bright and condensed at its centre, requiring a large instrument for its resolution here, but the outer parts are readily resolved by a four- to six-inch glass. The cluster is illustrated on page 537.

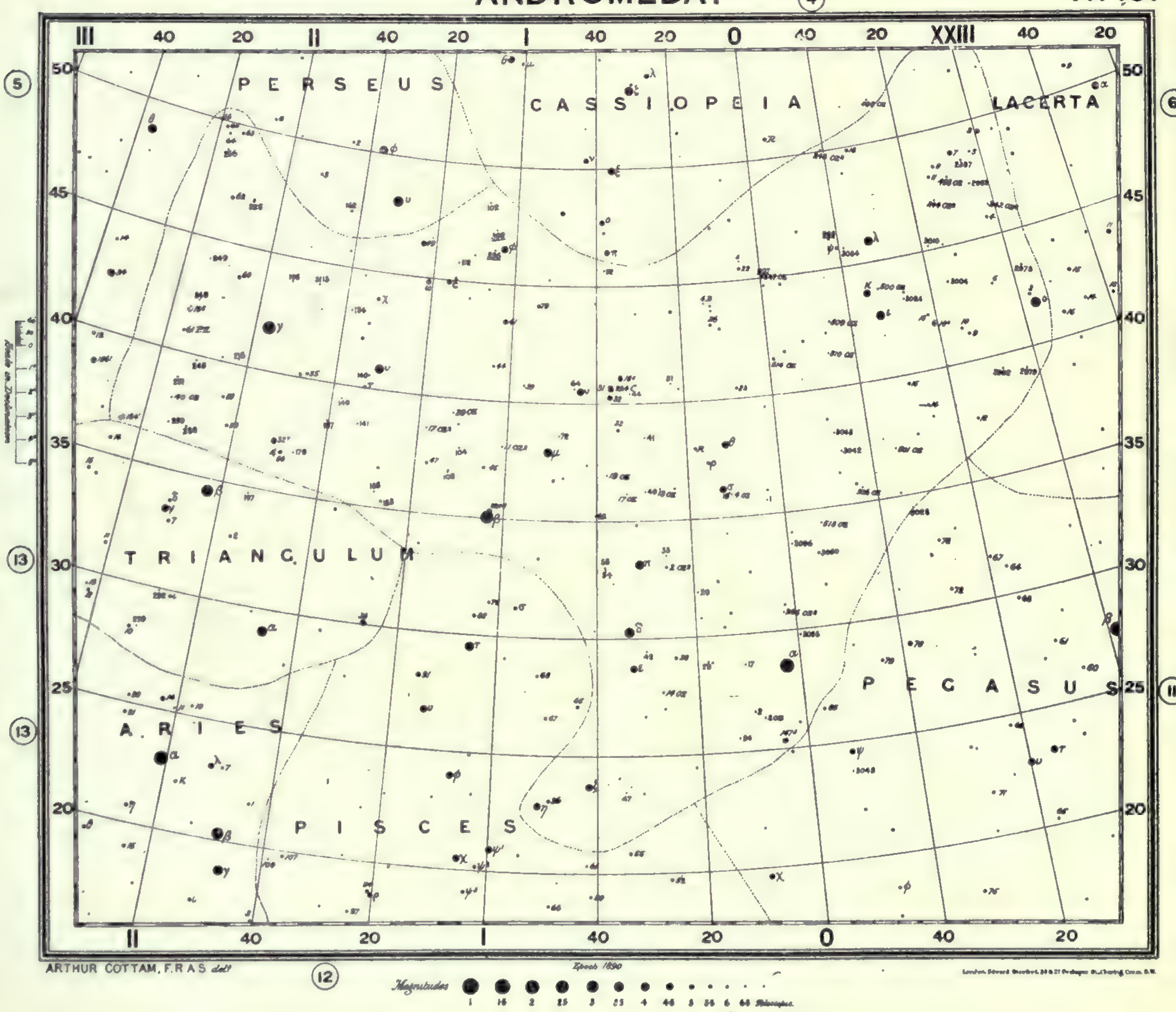
N.G.C. 7092 (39), (4681H), *Cygni*, 21*h*. 29·4*m*. + 48° 5′.

Typical open galactic cluster, just visible as a misty spot to the naked eye, and resolvable with opera glasses or a small finder. The component stars are not numerous, but are unusually bright for such an object. In this respect it is comparable to N.G.C. 2244 (which see).

†*N.G.C.* 7662 (4964H), (18[4]), *Andromedae*, 23*h*. 22·0*m*. + 42° 6′.

Bright slightly elliptical planetary nebula, blue in colour and about twenty seconds of arc in diameter. Appears nearly stellar with low powers. High magnification on an eight- or ten-inch telescope shows a dusky centre, giving an annular appearance to the nebula, which is brightest on the sides that are south of and following the dark space. The latter is occupied by a stellar nucleus which, though conspicuous on photographs, is only clearly seen with very large apertures. On the other hand, the outer borders of the nebula are relatively brighter visually than photographically. The effect of this is to make the object appear more nearly circular to the eye than would be expected

ANDROMEDA. No. 10.



from a study of photographs taken with short exposures, which only bring out the very elliptical internal portions surrounding the nucleus.

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VARIABLE STARS.

A few of the brighter variables are included on these charts, where they are indicated by black dots, surrounded by rings. None is shown which fails to reach the fifth magnitude at maximum and the diameters of the ring and dot indicate in each case the approximate brightness of the star at maximum and minimum respectively. There is nothing in the telescopic appearance of any variable to distinguish it from other stars of the same spectral type, but, for the benefit of those who may wish, out of curiosity, to watch the changes of light that take place in these interesting objects, a selected few are given below. They are sub-divided according to the recognised types described in Chapter XV. It will hardly be necessary to point out that the amateur, who wishes to make a serious and useful study of variable stars, must arm himself with special maps of the standard comparison stars for each object, together with a list of their magnitudes. These are to be obtained from the Director of the Variable Star Section of the British Astronomical Association, of which every observer intending to do serious work should become a member. It would be difficult to name any branch of astronomical work in which amateurs can obtain results of greater value to the science than in the study of variable stars; and the contributions of non-professional workers in the past have been responsible for the bulk of our knowledge of these objects. The latter are of all degrees of brightness, and work can thus be found for the smallest telescope or binocular, or even, in the case of the brightest variables, for the unaided eye.

Where a variable star does not already possess some simple designation, it is generally distinguished by one of the capital letters between R and Z, followed by the name of the constellation. In some constellations, however, there are more than nine variables, and in such cases the letters are doubled in the order RR, RS, . . . SS, ST, etc. In Cygnus there are so many known variables that even this duplex system is exhausted, and recourse is had to the earlier letters of the alphabet, from A to Q. These are not assigned singly, but in pairs, in the form AA, AB, . . . BB, BC . . . etc.

No list is here given of former Novæ; for, although many of them are still distinguishable in large instruments, most are beyond the reach of small apertures, and in any case could not be identified without special large-scale charts of their telescopic fields.

ECLIPSING VARIABLES.

[Positions for 1925·0.]

(*a*) ALGOL TYPE.

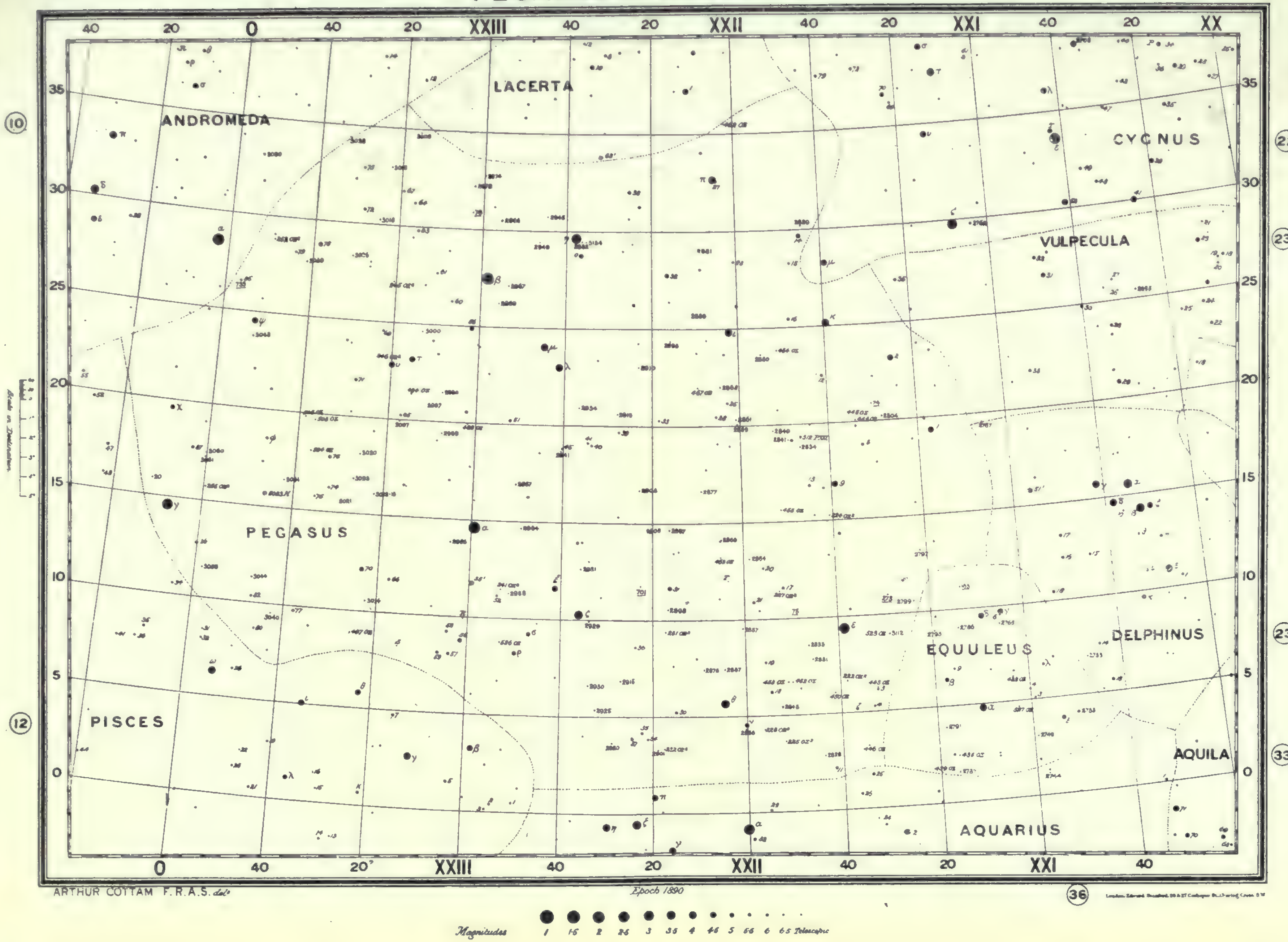
Star.	R.A.	Decl.	Range.	Period.	Duration of Eclipse.
	h. m.	° ′	*m. m.*	*d.*	*h.*
β Persei	3 3·3	+ 40 40	2·1 — 3·2	2·87	9·7
λ Tauri	3 56·5	+ 12 17	3·3 — 4·2	3·95	10·5
VV Orionis	5 29·7	− 1 12	5·8 — 6·2	1·49	3·6
WW Aurigae	6 27·5	+ 32 30	6·0 — 6·5	1·26	4·5
R Canis Majoris...	7 16·4	− 16 15	5·8 — 6·4	1·14	5·8
δ Librae	14 57·0	− 8 13	4·8 — 6·2	2·33	13·0
U Ophiuchi	17 12·7	+ 1 18	5·7 — 6·7	1·68	7·7

(*b*) β LYRAE TYPE.

Star.	R.A.	Decl.	Range.	Period.	Duration of Eclipse.
u Herculis	17 14·6	+ 33 11	4·8 — 5·3	2·05	—
β Lyrae	18 47·3	+ 33 16	3·4 — 4·1	12·91	—

PEGASUS & EQUULEUS.

No. 11.



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CEPHEIDS.

Star.	R.A.	Decl.	Range.	Period.	—
	h. m.	° ′	m. m.	d.	
SU Cassiopeiae	2 45·3	+ 68 35	5·9 — 6·3	1·95	—
T Monocerotis	6 21·2	+ 7 6	5·8 — 6·8	27·01	—
RT Aurigae	6 23·8	+ 30 33	4·9 — 5·9	3·73	—
ζ Geminorum	6 59·7	+ 20 41	3·7 — 4·1	10·15	—
X Sagittarii	17 42·8	— 27 48	4·4 — 5·0	7·01	—
Y Ophiuchi	17 48·6	— 6 8	6·0 — 6·7	17·12	—
W Sagittarii	18 0·2	— 29 35	4·3 — 5·1	7·59	—
Y Sagittarii	18 17·0	— 18 57	5·4 — 6·2	5·77	—
U Aquilae	19 25·3	— 7 12	6·2 — 6·9	7·02	—
η Aquilae	19 48·7	+ 0 49	3·7 — 4·5	7·18	—
S Sagittae	19 52·6	+ 16 26	5·4 — 6·1	8·38	—
T Vulpeculae	20 48·3	+ 27 58	5·5 — 6·4	4·44	—
δ Cephei	22 26·4	+ 58 2	3·6 — 4·3	5·37	—

LONG PERIOD VARIABLES.

R Andromedae	0 20·1	+ 38 10	5·6 — 14·9	407	—
o (Mira) Ceti	2 15·6	— 3 19	2·0 — 9·7	331	—
R Trianguli	2 32·5	+ 33 56	5·3 — 12·0	270	—
R Leporis	4 56·2	— 14 56	6·0 — 10·4	420	—
U Orionis	5 51·6	+ 20 10	5·4 — 12·3	374	—
R Geminorum	7 2·8	+ 22 50	5·9 — 13·8	370	—
R Leonis	9 43·5	+ 11 47	5·0 — 10·8	310	—
R Ursae Majoris	10 39·4	+ 69 10	5·9 — 13·6	298	—
SS Virginis	12 21·4	+ 1 11	6·0 — 9·0	355	—
T Ursae Majoris	12 33·0	+ 59 54	5·5 — 13·6	254	—
R Hydrae	13 25·6	— 22 54	3·5 — 10·1	406	—
S Virginis	13 29·1	— 6 49	5·8 — 12·7	372	—
R Boötis	14 33·9	+ 27 4	5·9 — 13·0	222	—
R Serpentis	15 47·2	+ 15 21	5·5 — 13·4	357	—
S Herculis	16 48·5	+ 15 4	5·9 — 12·5	300	—
R Aquilae	19 2·8	+ 8 7	5·4 — 11·8	310	—
R Cygni	19 34·8	+ 50 2	5·9 — 14·4	421	—
χ Cygni	19 47·7	+ 32 44	4·2 — 13·7	409	—
T Cephei...	21 8·5	+ 68 11	5·2 — 10·9	391	—
R Aquarii	23 39·9	— 15 42	6·0 — 10·8	380	—
R Cassiopeiae	23 54·6	+ 50 58	4·8 — 13·6	428	—

IRREGULAR VARIABLES.

α Orionis	5 51·1	+ 7 24	1·0 — 1·4	—	—
U Geminorum	7 50·7	+ 22 12	8·9 — 14·0	—	—
R Coronae Borealis	15 45·5	+ 28 23	5·5 — 12·5	—	—
R Scuti	18 43·5	— 5 47	4·8 — 7·8	—	—
SS Cygni	21 39·8	+ 43 14	8·4 — 12·0	—	—

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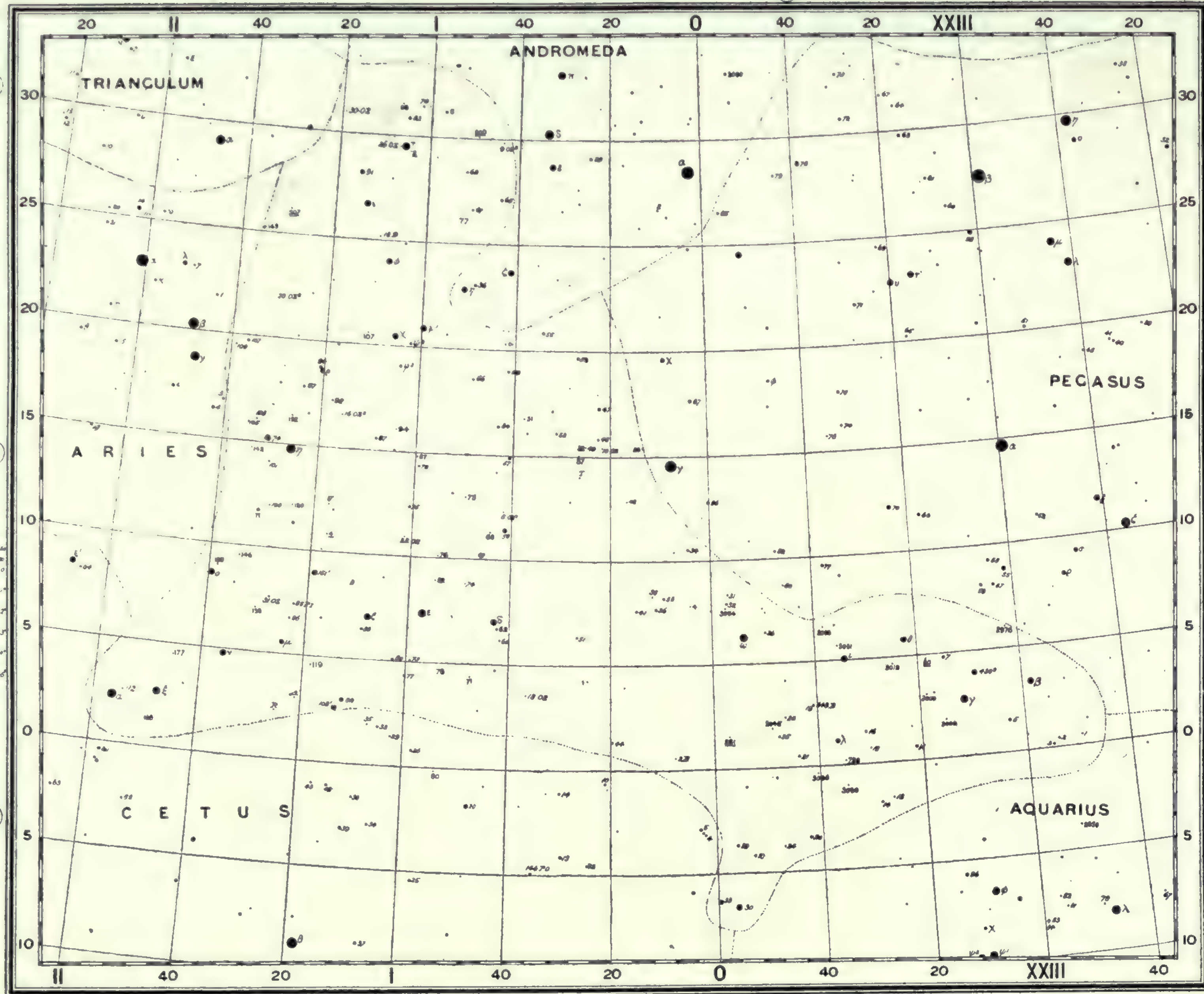
RED STARS.

Really vivid colours, with the exception of reds, are not to be observed among isolated stars. Blues and greens, more or less pronounced, are to be met with in the companions of certain doubles, but the tints are never very deep, and are probably due quite largely to the effects of contrast. It is otherwise with the red stars, for, although many objects so designated in astronomical text-books are more strictly of an orange, or even only yellowish orange tint, some are to be found which

PISCES.

No. 12.



ARTHUR COTTAM, F.R.A.S. del.

Epoch 1890

Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 Telescopic

really deserve the description applied to them. It is well, however, to state that very few particular shades of red are represented among the stars. The terms " crimson " and " ruby " are often to be met with in text-book descriptions, but these tints are never found pure in the heavens, except perhaps in Novae at certain stages of their decline. The red most commonly to be seen is that of a glowing ember, a red-hot poker, or the setting Sun. Mention of this may prepare the reader against disappointment, in case he expects to see stars that shine like the lamps of railway signals set at " danger." A large proportion of the reddest stars are long-period variables. Unfortunately, many of the finest are somewhat faint for small instruments, and in any case reflectors will deal more satisfactorily with them than refractors. The following short list gives but a sample of the many objects of their kind to be found in the sky. Nearly every star in it is of the maximum degree of redness that the telescope has yet revealed to us.

Star.	R.A. (1920).	Decl. (1920).	Magnitude.
	h. m.	° ′	*m.*
*B 4 Andromedae	0 15·7	+ 44 16	8·2
R Leporis (B 94)	4 56·0	− 14 56	6·0 − 10·4
R Leonis	9 43·3	+ 11 48	5·0 − 10·8
R Crateris (B 250)	10 56·6	− 17 53	8·0 − 9·0
SS Virginis (B 277)	12 21·1	+ 1 13	6·0 − 9·0
B 410 Ophiuchi	17 25·0	− 19 25	7·8
T Lyrae (B 448)	18 29·6	+ 36 56	7·2 − 7·8
V Aquilae (B 483)	19 0·1	− 5 48	6·5 − 8·0
B 521 Cygni	19 54·6	+ 44 2	8·2
RV Cygni (B 592)	21 40·0	+ 37 39	7·1 − 9·3

* B = Birmingham's Catalogue of Red Stars.

* * * * * * * * * * * *

LIST OF DOUBLE STARS.

The following list contains a number of the brighter pairs in various parts of the sky, and in most cases the component are not too close nor the differences in magnitude too great for the stars to be separately seen in instruments of quit moderate aperture.

Following the catalogue designation of the stars in Column 1 are given the constellations in which they are situated, wit Bayer's letters* and Flamsteed's numbers where they are available, and the numbers of the maps (in the case of stars N. o South Declination 40°), in which they will be found. Where obtainable, recent measures of the Position Angles and Distance have been given, together with the dates. In cases in which little or no relative motion has been shown, approximat positions are given without dates. In the column headed " Observer," the following abbreviations are used :—

Ait. = R. G. Aitken. Do. = J. W. Doberck. Jn. = E. L. Johnson. Lv. = F. P. Leavenworth. Ph. = T. E. R. Phillips Gr. means that the star was measured at the Royal Observatory, Greenwich ; Ed. that it was measured at the Roya Observatory, Edinburgh ; La P. that it was measured at the University Observatory, La Plata ; and C.O. that th measures are taken from a list of Southern Doubles compiled by Dr. R. T. A. Innes, and published in the sixth Edition o Webb's *Celestial Objects for Common Telescopes.*

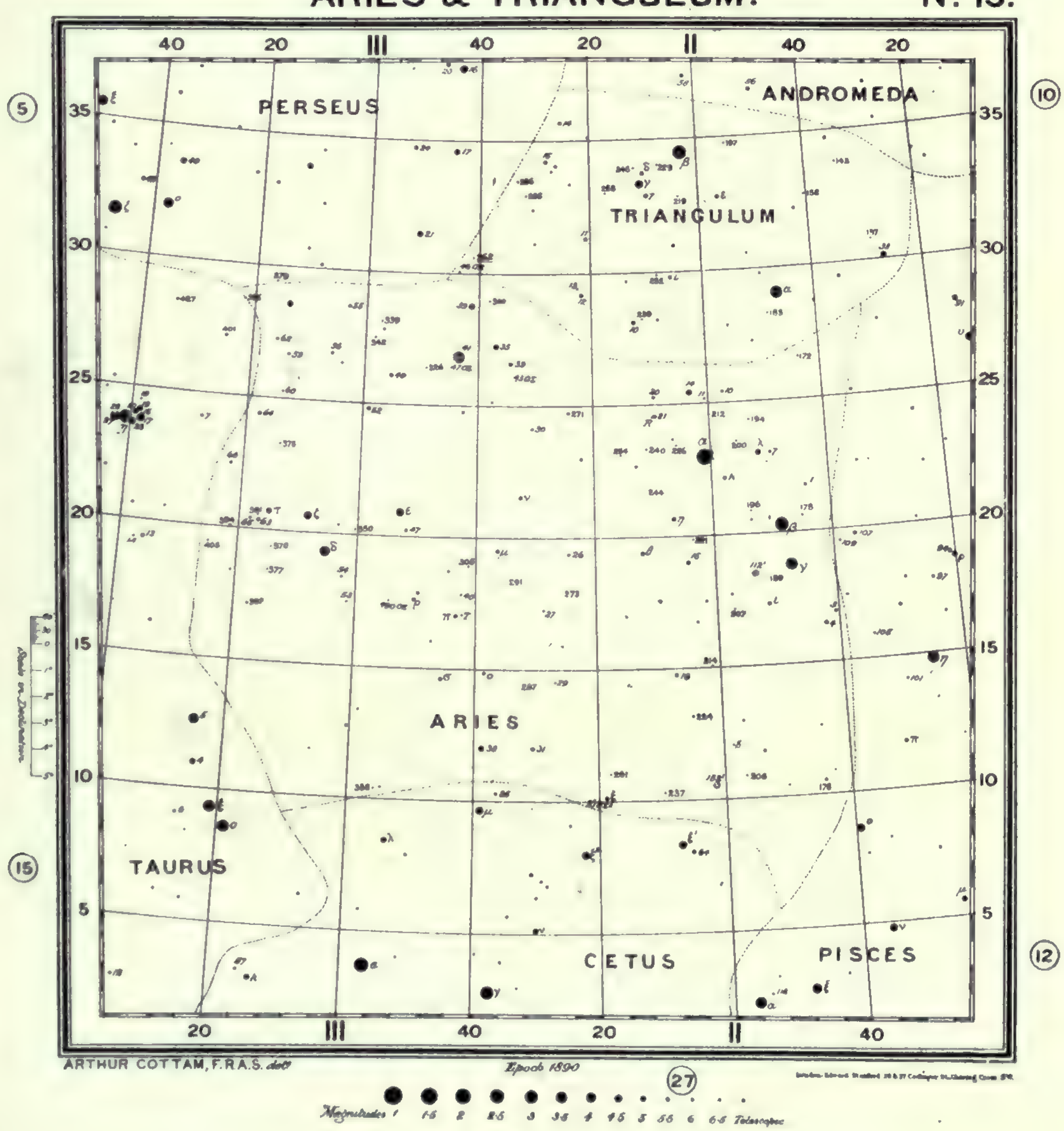
* For Greek Alphabet, see p. 919.

Star and Constellation.		Map.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
Σ 3060	- Pegasi ...	11	0 2·0	+17 40	8·5, 8·7	121·3	3·5	1921·9	Ph.	– –
OΣ 12	λ Cassiopeiae	4	0 27·6	+54 6	5·5, 5·8	158·9	0·6	1923·1	Ph.	Binary.
	λ Sculptoris	...	0 36·4	−39 5	6·7, 6·8	344·2	0·6	1919·9	La P.	——
Σ 60	η Cassiopeiae	4	0 44·0	+57 23	3·7, 7·4	261·9	7·6	1922·6	Ph.	Binary. Period, 328 years.
Σ 73	36 Andromedae	10	0 50·7	+23 12	6·2, 6·8	56·0	0·7	1921·7	Ait.	Binary. Period, 124 years.
Sellors 1	β Phœnicis ...	...	1 2·5	−47 9	3·3, 3·3	5·7	1·7	1920·9	La P.	Binary.
Σ 100	ζ Piscium ...	12	1 9·5	+ 7 9	4·2, 5·3	63·5	23·5	...	...	No relative motion.

List of Double Stars—*continued.*

Star and Constellation.		Map.	1920. R.A.	1920. Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
h 3423	κ Toucani ...	...	1 13·0	−69 18	5·0, 7·7	346·4	5·4	1920·8	La P.	Binary. Distance nearly constant.
Σ 113	42 Ceti ...	27	1 15·7	− 0 55	6·2, 7·2	357·3	1·5	1921·8	Do.	—
Σ 93 (Polaris)	α Ursae Minoris	1	1 31·7	+88 53	2, 9	216	18·2	...	...	Larger star a spectroscopic binary and slightly variable. The companion a test for small apertures, but easy with two and a half inches
Σ 138	— Piscium ...	12	1 31·9	+ 7 16	7·3, 7·3	42·7	1·6	1920·9	Lv.	—
Dunlop 5	p Eridani ...	...	1 36·7	−56 36	5·3, 5·4	213·4	9·1	1922·0	Jn.	Binary. Period, 219 years.
Σ 147	— Ceti ...	27	1 37·8	−11 43	5·3, 6·9	88	3·6	...	...	No relative motion.
Σ 163	— Cassiopeiae	4	1 45·4	+64 28	6·2, 8·2	34	35	...	...	Gold and blue, striking contrast. No relative motion.

ARIES & TRIANGULUM. No 13.



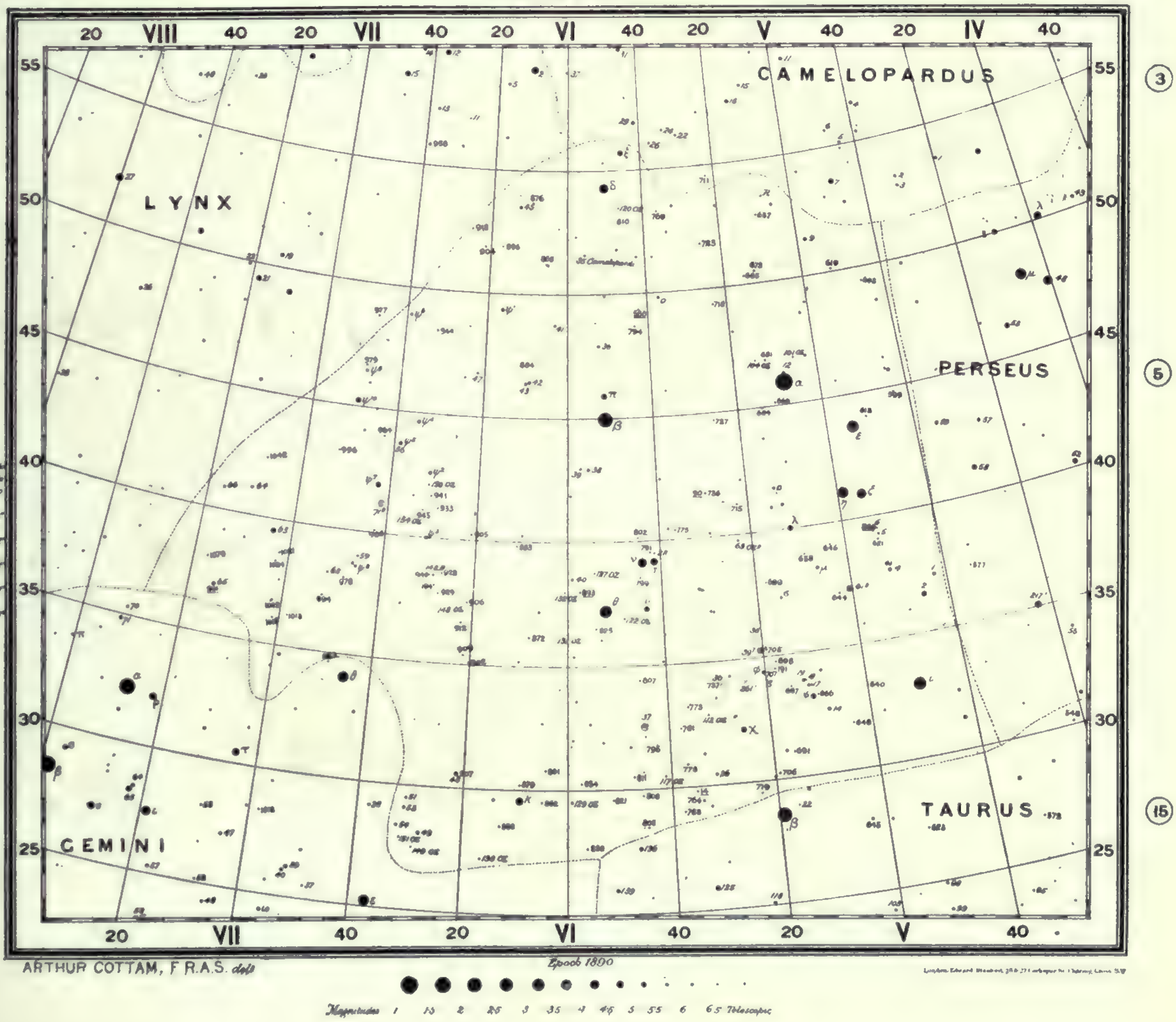
LIST OF DOUBLE STARS—*continued.*

STAR AND CONSTELLATION.		MAP.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	REMARKS.
			h. m.	° ′		°	″			
Σ 178	— Arietis ...	13	1 47·8	+10 25	7·8, 7·8	198·9	3·0	1914·7	Acocks	——
Σ 180	γ Arietis ...	13	1 49·1	+18 54	4·2, 4·4	359·9	8·1	1919·8	Ph.	Beautiful pair.
Σ 186	— Piscium ...	12	1 51·7	+ 1 27	7·2, 7·2	41·6	1·1	1921·9	Do.	——
h 3475	— Eridani ...	...	1 52·7	−60 43	6·5, 6·9	55·4	2·6	1920·9	La P.	Angle slowly increasing.
β 513	48 Cassiopeiae	4	1 55·3	+70 31	5·0, 7·5	202·6	0·7	1921·7	Ait.	Binary. Period, 53 years.
Σ 202	α Piscium ...	12	1 57·9	+ 2 23	2·8, 3·9	309·7	2·5	1922·0	Lv.	——
Σ 205	γ Andromedae	10	1 59·0	+41 51	3, 5	62·3	9·9	1918·0	Ait.	Gold and greenish blue; beautiful contrast
OΣ 38	γ^2 Andromedae	10	1 59·0	+41	5·4, 6·6	105·7	0·6	1921·6	Ait.	Binary. Period, 55 years.
Σ 227	ι Trianguli ...	13	2 7·7	+29 56	5·0, 6·4	73·2	3·6	1911·3	Gr.	Yellow and blue. Beautiful pair.
Σ 231	66 Ceti ...	27	2 8·7	− 2 46	6·0, 7·8	232	15·5	...	...	Very little relative motion. Yellowish and blue
Σ 228	— Andromedae	10	2 8·9	+47 6	6·7, 7·6	122·3	0·6	1921·9	Do.	Binary. Period, 167 years.
Σ 262	ι Cassiopeiae	4	2 22·4	+67 3	4·2, 7·1	250·6 111·8	2·1 7·4 }	1914·9	Ph.	Fine triple.
h 3527	— Eridani ...	...	2 40·2	−40 52	6·3, 6·5	42·9	2·1	1919·9	La P.	——
Σ 299	γ Ceti ...	27	2 39·2	+ 2 54	3·0, 6·8	292	3	...	...	Very little relative motion.
Σ 311	π Arietis ...	13	2 44·8	+17 8	4·9, 8·4	117·7	3·0	1912·4	Gr.	——
Σ 318	20 Persei ...	5	2 48·6	+38 1	5·5, 10	237	14	...	...	Test for small telescopes.
Σ 333	ε Arietis ...	13	2 54·6	+21 2	5·7, 6·0	203·0	1·4	1921·7	Ph.	——
	θ Eridani ...	...	2 55·2	−40 37	3·1, 4·1	87·3	7·8	1922·0	Jn.	Spectroscopic binary.
Σ 346	52 Arietis ...	13	3 0·7	+24 57	6·0, 6·0	356·7	5·2	1921·7	Ph.	——
I 55	— Eridani ...	...	3 9·6	−44 4	5·9, 6·7	158·9	0·7	1920·9	La P.	Colours well contrasted.
Σ 422	— Tauri ...	15	3 32·7	+ 0 20	6·0, 8·2	254·1	6·4	1902·0	Thiele	Binary of long period. Placed 10° too fa north on Map.
Σ 425	— Persei ...	5	3 35·1	+33 52	7·3, 7·3	89·2	2·4	1914·9	Ph.	——
OΣ 65	— Tauri ...	15	3 45·5	+25 20	6·5, 6·8	210·7	0·6	1922·1	Do.	——
Dunlop 16	f Eridani ...	...	3 45·6	−37 53	4·4, 5·0	208·7	7·8	1919·9	La P.	——
Σ 470	32 Eridani ...	26	3 50·3	− 3 12	4·0, 6·0	348	6·7	...	...	Very fine colours. Topaz and light green. No relative motion.
Russ. 38	— Octantis ...	...	4 0·5	−85 31	6·5, 7·7	245·0	2·3	1900	C.O.	——
	θ Reticuli ...	...	4 16·6	−63 27	6·1, 8·2	6·5	3·6	1902	C.O.	——
Rümk. 4	— Doradûs ...	...	4 22·3	−57 15	6·5, 6·8	237·9	5·7	1902	C.O.	——
	θ Tauri ...	15	4 24·0	+15 48	4·7, 5·0	346	337	...	...	Naked eye pair.
Σ 550	ι Camelopardi	3	4 25·7	+53 45	5·1, 6·2	307	10	...	...	——
Σ 559	— Tauri ...	15	4 28·9	+17 51	7·0, 7·0	278	3	...	...	No relative motion.
Σ 572	— Tauri ...	15	4 33·5	+26 47	6·5, 6·5	200·2	3·7	1910·0	Gr.	——
h 3683	— Doradûs ...	...	4 38·7	−59 6	6·4, 6·5	72·2	0·6	1920·9	La P.	——
Σ 590	55 Eridani ...	26	4 39·7	− 8 56	6·2, 6·7	31	9	...	...	——
Σ 616	ω Aurigae ...	14	4 53·8	+37 47	4·0, 7·9	353·9	5·8	1904·2	Gr.	Colour estimates discordant.
Σ 627	— Orionis ...	24	4 56·4	+ 3 30	6·3, 7·0	258·4	20·6	1915	Franks	——
OΣ 95	— Tauri ...	15	5 0·8	+19 42	6·6, 7·2	320·6	0·9	1919·9	Ph.	——
Σ 644	— Aurigae ...	14	5 4·9	+37 12	6·7, 7·0	219·4	1·6	1909·9	Gr.	Greenish blue and red. Colours remarkable.
OΣ 98	14 Orionis ...	24	5 3·5	+ 8 23	6·0, 6·8	134·3	0·8	1921·8	Ait.	——
Σ 661	κ Leporis ...	28	5 9·5	−13 2	5·0, 7·9	359	2·6	...	...	No relative motion. Yellowish and bluish.
Σ 668 (Rigel)	β Orionis ...	24	5 10·7	− 8 17	0·3, 6·7	202	9·5	...	...	Bluish. Test for two-inch telescope.
Dawes 5	η Orionis ...	24	5 20·5	− 2 28	3·8, 4·8	78·6	1·3	1921·5	Ait.	Test for four-inch telescope.
Σ 716	118 Tauri ...	15	5 24·3	+25 5	5·8, 6·6	201·4	4·7	1915·9	Ph.	——
h 3766	α Leporis ...	28	5 29·2	−17 53	4·0, 9·5	156·1	35·4	...	...	Fine field for small telescopes, with other pairs
Σ 738	λ Orionis ...	24	5 30·7	+ 9 53	4·0, 6·0	43	4·5	...	...	No relative motion. Very fine region.
Σ 752	ι Orionis ...	24	5 31·5	− 5 57	3·2, 7·3	142	11·3	...	...	No relative motion.
Σ 749	— Tauri ...	15	5 31·9	+26 53	7·1, 7·2	344·0	1·0	1922·1	Ph.	——
Σ 762	σ Orionis ...	24	5 34·7	− 2 38	...	...	...	...	...	Very beautiful multiple group, with striking colours.
Σ 774	ζ Orionis ...	24	5 36·7	− 1 58	2·0, 5·7	158·8	2·4	1913·2	Gr.	Disagreement as to colour of smaller star.
OΣ 545	θ Aurigae ...	14	5 54·3	+37 13	3·3, 7·5	335·1	2·6	1919·7	Ph.	Test for four-inch telescope.
Σ 845	41 Aurigae ...	14	6 5·5	+48 44	5·2, 6·4	353	8	...	...	No relative motion.

List of Double Stars—*continued.*

Star and Constellation.		Map.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
Σ 872	— Aurigae ...	14	6 10·3	+36 11	6·0, 7·0	217	11	...	...	No relative motion.
Σ 900	8 Monocerotis	25	6 19·5	+ 4 38	4·0, 6·7	25	13·5	...	...	Yellow and bluish. Very fine low-power field.
Σ 919	11 Monocerotis	25	6 24·9	− 6 58	5·0, 5·5	132·8	7·2	1911·1	Gr.	Very beautiful group.
					6·0	106·1	2·5			
L 2333	— Puppis ...	...	6 27·9	−50 11	5·3, 5·3	261·1	0·6	1903	C.O.	—
Σ 924	20 Geminorum	16	6 27·6	+17 51	6·0, 6·9	210	20	...	...	Yellow and blue. Fine field.
β 755	— Columbae	...	6 32·6	−36 43	5·6, 6·6	258·1	1·3	1920·0	La P.	—
OΣ 152	54 Aurigae ...	14	6 34·5	+28 20	6·0, 7·8	33·2	0·8	1912·7	Gr.	—
Σ 945	— Aurigae ...	14	6 34·7	+41 4	7·1, 8·0	268·6	0·7	1914·9	Ph.	—
Σ 948	12 Lyncis ...	7	6 39·2	+59 32	5·2, 6·1	108·2	1·8	1921·7	Ph.	—
Dunlop 32	— Puppis ...	...	6 39·6	−38 19	6·3, 7·7	276·8	8·2	1920·0	La P.	—

AURIGA. No. 14.



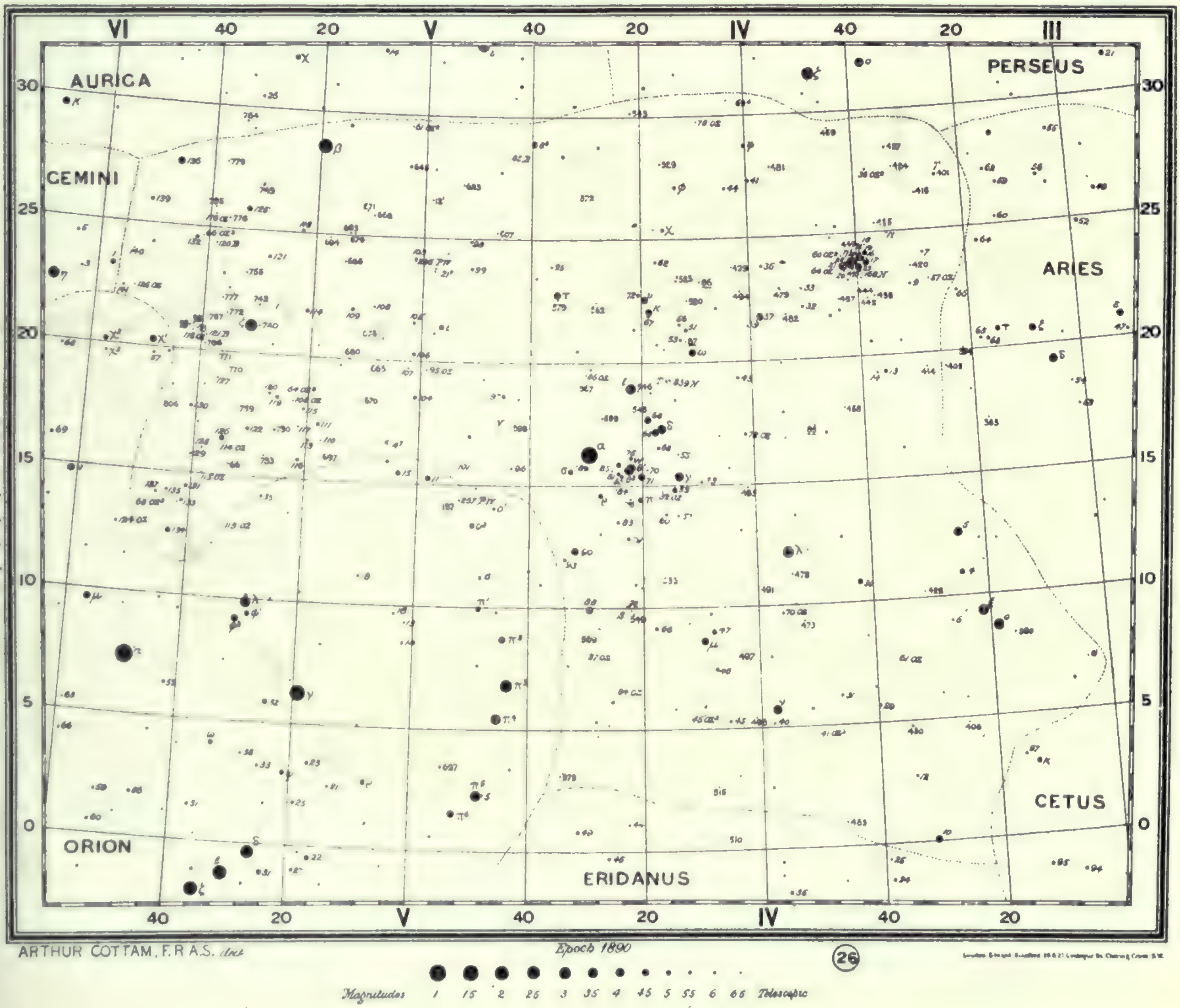
List of Double Stars—*continued.*

Star and Constellation.		Map.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
Sirius	α Canis Maj.	28	6 41·6	−16 35	−1·6, 8·4	62·4	11·2	1922·1	Ph.	Binary. Period, 49 years.
OΣ 156	— Geminorum	16	6 42·7	+18 17	6·5, 7·0	293·4	0·5	1911·7	Gr.	—
Σ 982	38 Geminorum	16	6 50·1	+13 17	5·4, 7·7	157·0	6·5	1914·9	Ph.	—
Σ 997	μ Canis Maj.	28	6 52·4	−13 56	4·7, 8·0	334·5	2·3	1901	Do.	Yellow and blue.
	ε Canis Maj.	28	6 55·5	−28 51	2, 9	161	7·5	...	...	—
Dunlop 39	— Carinae ...	...	7 2·0	−59 4	5·7, 6·9	80·7	1·9	1912	C.O.	—
h 3928	— Puppis ...	...	7 2·6	−34 40	6·3, 7·4	153·7	3·9	1920·1	La P.	—
	γ Volantis ...	...	7 9·5	−70 22	3·7, 5·5	299·4	13·7	1922·2	Jn.	—
Σ 1066	δ Geminorum	16	7 15·3	+22 8	3·2, 8·2	209·9	6·7	1912·3	Gr.	Pale yellow and reddish.
Rümk. 6	— Carinae ...	...	7 18·4	−52 10	5·9, 6·5	21·0	8·8	1902	C.O.	—
	σ Argûs ...	...	7 26·7	−43 9	3·3, 7·9	73·8	22·4	1922·2	Jn.	—
Σ 1110 (Castor)	α Geminorum	16	7 29·5	+32 4	2·7, 3·7	214·7	4·6	1923·0	Ph.	Binary. Period, 347 years. Magnificent pair. Each component a spectroscopic binary.
H*h*. 269	— Puppis ...	28	7 30·9	−23 18	6, 6	110	9	...	...	—
Σ 1121	— Puppis ...	28	7 32·9	−14 18	7·2, 7·2	304	7·5	...	...	—
h 273	κ Puppis ...	...	7 35·5	−26 37	4·1, 4·1	318	10	...	...	—
Σ 1126	— Canis Min.	25	7 35·8	+ 5 24	7·2, 7·5	149·6	1·1	1923·0	Ph.	—
h 3997	— Volantis ...	...	7 37·0	−74 6	6·5, 6·6	115·3	2·1	1921·0	La P	—
Σ 1138	2 Puppis ...	28	7 41·8	−14 30	6·2, 7·0	339	16·5	...	...	White and pale blue.
OΣ 182	— Canis Min.	25	7 48·5	+ 3 36	7·0, 7·5	32·1	0·9	1912·2	Gr.	—
Σ 1177	— Cancri ...	17	8 0·7	+27 45	6·5, 7·4	351·5	3·5	1910·7	Gr.	Little or no relative motion.
Dunlop 63	— Puppis ...	...	8 7·1	−42 24	6·4, 7·4	80·9	5·5	1907	C.O.	—
Σ 1196	ζ Cancri ...	17	8 7·6	+17 54	5·0, 5·7	256·9	0·7	1923·0	Ph.	Binary. Period, 60 years. A third star at 113°·2, 4″·8 (A.C.°) Ph. 1916.
Dunlop 66	ε Volantis ...	...	8 7·5	−68 24	4·5, 8·0	22·2	6·1	1922·3	Jn.	—
Σ 1223	φ² Cancri ...	17	8 22·0	+27 12	6·0, 6·5	216	4·9	...	...	—
β 205	— Mali ...	...	8 29·1	−24 16	6·9, 7·0	205·0	0·5	1917·1	Ait.	Test for ten-inch telescope.
Σ 1245	— Hydrae ...	30	8 31·6	+ 6 54	6·0, 7·0	25	10·3	...	...	No relative motion. Star omitted from Map.
β 208	Pyxis ...	30	8 35·1	−22 29	5·2, 8·5	196·9	1·0	1917·1	Ait.	
h 4128	— Carinae ...	...	8 37·5	−60 2	6·4, 7·1	217·1	1·6	1912	C.O.	—
Σ 1270	— Hydrae ...	30	8 41·3	− 2 19	6·6, 7·6	260	4·7	...	...	No relative motion.
Σ 1268	ι Cancri ...	17	8 41·9	+29 3	4·0, 6·5	307	30	...	...	Yellow and blue. Beautiful contrast.
	δ Argûs (Velorum) ...	...	8 42·2	−54 24	2·1, 5·2	156·9	3·5	1922·4	Jn.	—
Σ 1273	ε Hydrae ...	30	8 42·5	+ 6 43	3·8, 7·8	244·0	3·1	1922·2	Do.	The brighter star a close double. Rapid binary. Period, 15 years : 175°·6, 0″·25: Ait. 1921·8.
Rümk. 9	— Carinae ...	...	8 43·2	−58 26	6·3, 6·7	295·1	4·2	1902	C.O.	—
Σ 1291	— Cancri ...	17	8 49·4	+30 53	5·9, 6·4	322·5	1·4	1912·8	Gr.	Crocus yellow. This is the star called ι² on the Map.
Σ 1295	17 Hydrae ...	30	8 51·6	− 7 40	7·2, 7·3	359	4·3	...	...	No relative motion.
	H Velorum ...	...	8 53·9	−52 25	4·8, 7·8	338·2	2·9	1922·3	Jn.	Striking contrast in colours.
h 4165	— Velorum ...	...	8 58·3	−51 53	5·4, 7·4	105·4	1·2	1920·3	La P.	—
h 4188	— Velorum ...	...	9 9·5	−43 17	5·7, 6·2	282	3·1	1902	C.O.	—
Σ 1356	ω Leonis ...	19	9 24·2	+ 9 25	6·2, 7·0	130·4	1·0	1922·3	Ph.	Binary. Period, 116 years.
OΣ 208	φ Ursae Maj.	8	9 46·7	+54 27	5·2, 5·5	324·1	0·5	1921·3	Ait.	Test for ten-inch telescope. Binary. Period, 100 years.
Dunlop 78	ζ¹ Antliae ...	30	9 27·3	−31 32	5·9, 6·7	211·1	8·2	1919·7	La P.	Star entered in Map as ξ¹.
	ψ Argûs (Velorum)	...	9 27·5	−40 7	3·6, 5·6	154·9	1·1	1922·3	Innes	Binary.
h 4220	— Velorum ...	...	9 30·9	−48 39	5·4, 6·0	210·0	3·7	1908	C.O.	—
	υ Argûs (Carinae)	...	9 45·1	−64 41	3·1, 3·9	127·8	5·1	1918·4	La P.	—
	8 Sextantis ...	30	9 48·5	− 7 43	5·5, 5·7	64·6	0·6	1921·3	Ait.	Binary.
Harg. 47	— Carinae ...	...	10 1·1	−61 29	6·3, 7·8	353·8	1·4	1899	C.O.	—
Σ 1424	γ Leonis ...	19	10 15·5	+20 15	2·6, 3·8	117·9	3·8	1923·0	Ph.	Very fine pair. Binary. Period, 407 years.

LIST OF DOUBLE STARS—*continued.*

Star and Constellation.		Map.	1920. R.A.	1920. Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
	S Velorum ...	...	10 28·5	−44 39	5·6, 5·9	217·4	13·3	1903	C.O.	——
Σ 1466	35 Sextantis...	30	10 39·2	+ 5 10	6·1, 7·2	240	6·6	...	...	No relative motion.
	μ^2 Argûs (Velorum)	...	10 43·3	−48 59	2·8, 6·3	61·6	2·5	1900	C.O.	Fine colour contrast.
	δ Chamelionis	...	10 44·5	−80 2	5·5, 5·8	65·3	0·6	1912	C.O.	——
Russ. 161	— Carinae ...	...	10 46·2	−58 54	6·1, 7·1	271·6	1·6	1897	C.O.	Angle increasing slowly.
Σ 1487	54 Leonis ...	19	10 51·3	+25 10	5·0, 7·0	107·0	6·5	1910·8	Gr.	——
4423	— Centauri ...	...	11 12·7	−45 26	6·5, 6·8	280·4	2·6	1913	C.O.	——
Σ 1523	ξ Ursae Maj.	8	11 14·4	+32 0	4·0, 4·9	99·2	2·8	1922·2	Do.	Binary. Period, 60 years.
	π Centauri ...	...	11 17·4	−54 3	4·3, 5·7	140·3	0·6	1914·9	Voûte	——
Σ 1536	ι Leonis ...	19	11 19·7	+10 59	3·9, 7·1	37·4	1·7	1920·3	Lv.	——

TAURUS. No. 15.



ARTHUR COTTAM, F.R.A.S. delt

Epoch 1890

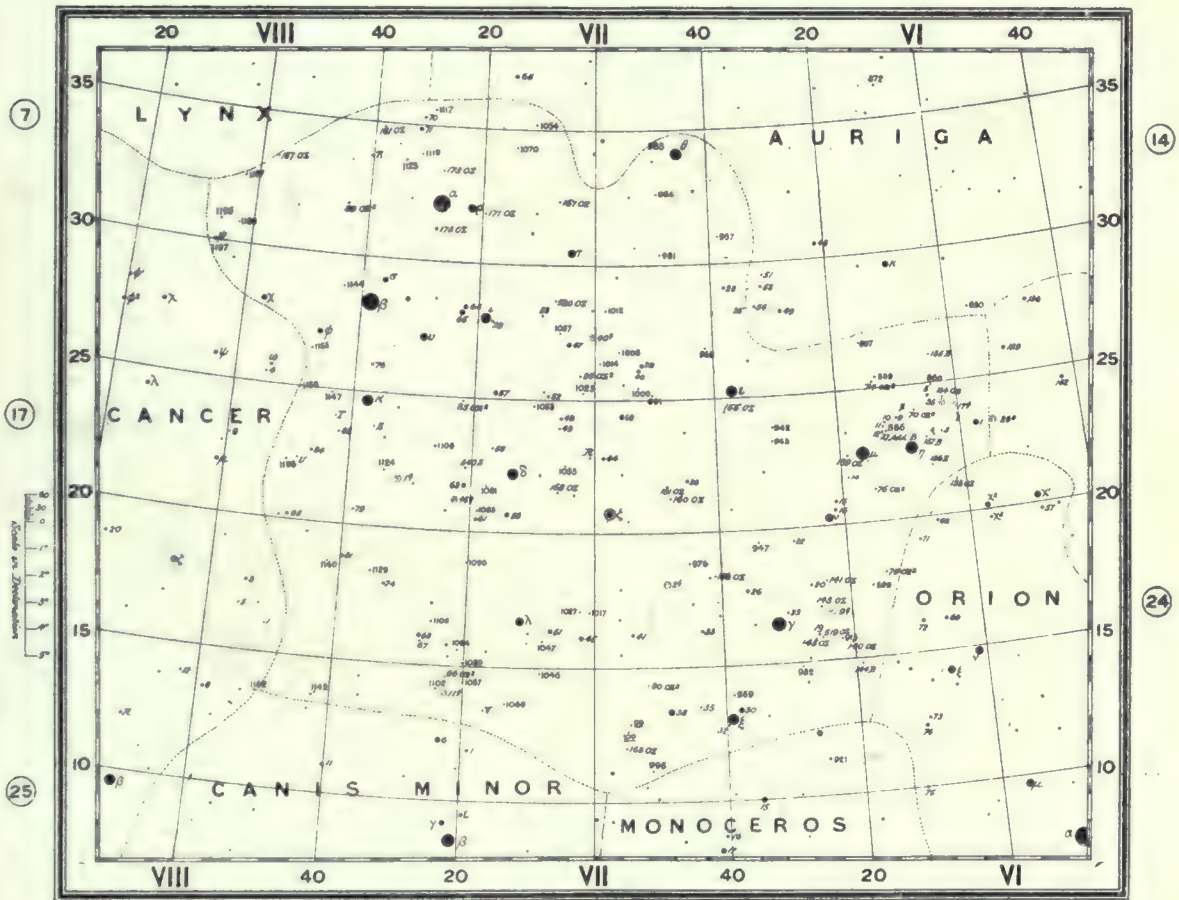
List of Double Stars—*continued*.

Star and	Constellation.	Map.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
h 4432	— Carinae ...	...	11 19·9	−64 31	5·3, 6·5	299·5	2·5	1918·4	La P.	—
Σ 1540	83 Leonis ...	19	11 22·8	+ 3 27	6·3, 7·3	150	29·6	...	...	Smaller star ruddy.
Jacob 6	— Hydrae ...	31	11 25·7	−24 1	6·0, 6·0	77	8	...	...	—
I 78	— Centauri ...	...	11 29·7	−40 9	5·5, 5·6	89·4	1·2	1910	C.O.	—
h 4478	β Hydrae ...	31	11 48·9	−33 27	4·4, 4·8	355·8	1·4	1919·5	La P.	—
	ε Chamelionis	...	11 55·6	−77 47	5·0, 5·8	182·8	1·1	1922·5	Jn.	—
Σ 1596	2 Comae Ber.	9	12 0·2	+21 55	6·0, 7·5	339	3·7	...	...	No relative motion.
h 4498	— Muscae ...	...	12 2·2	−65 16	6·0, 7·7	61·6	8·7	1902	C.O.	—
	D Centauri ...	...	12 9·8	−45 17	5·3, 6·5	246·0	3·1	1922·5	Jn.	—
β 920	Corvi ...	31	12 11·6	−22 54	6·5, 7·0	257·1	1·2	1905	Doolittle	Star not on Map.
Russ. 193	Centauri ...	...	12 13·6	−35 39	6·3, 6·7	166·3	1·1	1910	C.O.	—
Σ 1627	Virginis ...	29	12 14·1	− 3 30	5·9, 6·4	196	20	...	...	No relative motion.
Σ 1633	Comae Ber.	9	12 16·7	+27 31	7·1, 7·2	245	8·8	...	...	No relative motion.
Σ 1639	Comae Ber.	9	12 20·4	+26 2	6·7, 7·9	337·5	0·6	1923·1	Ph.	Binary. Period, 361 years.
	α Crucis ...	...	12 22·1	−62 40	1·0, 1·5	113·8	4·9	1922·5	Jn.	No relative motion yet observed.
H*h*. 396	δ Corvi ...	31	12 25·7	−16 4	3·0, 8·5	214	24·3	...	...	Yellowish white and lilac.
Σ 1657	24 Comae Ber.	9	12 31·2	+18 49	4·7, 6·2	271	20·2	...	...	No relative motion. Yellow and very blue.
	γ Centauri ...	...	12 37·0	−48 32	2·4, 2·4	359·0	0·8	1921·3	La P.	Binary. Period, 203 years.
Σ 1669	— Corvi ...	31	12 37·1	−12 33	6·5, 6·5	301	5·7	...	...	No relative motion.
Σ 1670	γ Virginis ...	29	12 37·7	− 1 0	3·6, 3·7	322·3	5·8	1922·2	Do.	Fine binary. Period, 194 years.
	ι Crucis ...	...	12 41·2	−60 34	4·8, 7·8	27·0	26·4	1922·5	Jn.	—
Russ. 207	β Muscae ...	...	12 41·3	−67 41	3·3, 3·6	357·0	1·2	1922·5	Jn.	—
Σ 1687	35 Comae Ber.	9	12 49·4	+21 41	5·0, 7·8	96·7	1·0	1921·3	Ph.	—
Σ 1692 (Cor Caroli)	12 Canum Ven.	9	12 52·3	+38 45	3·2, 5·7	227·8	19·7	1919·5	Ph.	—
β 929	48 Virginis ...	29	12 59·8	− 3 14	6·2, 6·2	209·0	0·5	1919·4	Gr.	—
Russ. 213	— Centauri ...	...	13 2·5	−59 26	6·1, 6·3	26·0	0·8	1912	C.O.	—
	θ Muscae ...	...	13 2·9	−64 52	5·6, 7·0	186·0	5·6	1922·5	Jn.	—
Sellors 18	— Centauri ...	...	13 18·1	−47 31	6·3, 7·2	224·0	0·8	1895	C.O.	—
Σ 1744 (Mizar)	ζ Ursae Maj.	8	13 20·7	+55 20	2·1, 4·2	150·1	14·4	1919·5	Ph.	The first double star discovered (by Ricciolo), the first photographed (by Bond), the brighter component the first discovered spectroscopic binary. ζ and Alcor form a naked-eye pair.
ΟΣΣ 123	— Draconis ...	1	13 24·4	+65 10	6·4, 6·8	147	6·9	...	...	Yellowish and blue.
Σ 1768	25 Canum Ven.	9	13 33·9	+36 42	5·7, 7·6	119·9	1·5	1920·3	Ph.	White and blue. Binary. Period, 220 years.
	Q Centauri ...	...	13 36·6	−54 9	5·4, 6·8	165·7	5·0	1909	C.O.	—
Σ 1777	84 Virginis ...	29	13 39·1	+ 3 57	5·8, 8·2	230·8	3·3	1913·3	Acocks	—
	N Centauri ...	...	13 46·9	−52 25	5·4, 7·4	288·7	18·2	1897	C.O.	—
	κ Centauri ...	...	13 47·2	−32 36	4·5, 5·9	110·3	7·6	1922·5	Jn.	—
β 343	...	...	13 47·4	−31 13	6·2, 7·0	112·8	1·2	1910	C.O.	—
	h Centauri ...	...	13 48·6	−31 32	4·8, 6·3	183·8	4·3	1903	C.O.	—
	η Centauri ...	...	13 48·6	−35 16	5·6, 5·8	93·2	1·0	1910	C.O.	—
Russ. 227	— Centauri ...	...	13 51·1	−53 42	6·4, 7·4	357·2	1·4	1911	C.O.	—
Dunlop159	— Centauri ...	...	14 16·8	−58 5	4·9, 6·9	162·1	9·8	1902	C.O.	—
Σ 1833	— Virginis ...	29	14 18·4	− 7 24	7·0, 7·0	168	5·6	...	...	Very little relative motion.
Σ 1835	— Boötis ...	20	14 19·4	+ 8 49	5·5, 6·8	190	6·3	...	...	—
	α Centauri ...	...	14 34·3	−60 30	0·1, 1·5	226·6	12·7	1922·5	Jn.	The second nearest star to the Solar System. Splendid binary. Period, 80 years.
Σ 1864	π Boötis ...	2	14 37·0	+16 46	4·9, 6·0	104·5	5·7	1921·6	Ph.	—
Σ 1865	ζ Boötis ...	20	14 37·5	+14 5	3·5, 3·9	137·8	0·9	1921·4	Ait.	Binary. Period, 130 years. Test for five and a half inch telescope.
Σ1877	ε Boötis ...	20	14 41·5	+27 21	3·0, 6·3	329·9	2·7	1921·5	Ph.	Yellow and bluish. Test for two-inch telescope.
β 106	μ Librae ...	34	14 44·9	−13 49	5·5, 6·3	333·2	1·5	...	...	—
Σ 1888	ξ Boötis ...	20	14 47·7	+19 26	4·7, 6·6	48·8	3·0	1923·2	Ph.	Binary. Period, 160 years.
β 239	59 Hydrae ...	31	14 53·9	−27 20	6·0, 6·0	321·0	1·0	1908	Doolittle	—

LIST OF DOUBLE STARS—*continued.*

Star and Constellation.		Map.	1920. R.A.	1920. Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
	π Lupi ...	...	14 59·6	−46 45	4·0, 4·2	82·4	1·4	1922·6	Jn.	——
Σ 1909	44 Boötis ...	20	15 1·2	+47 58	5·2, 6·1	243·7	3·7	1919·6	Lv.	——
	μ Lupi ...	...	15 12·9	−47 34	4·5, 4·9	150·8	1·5	1922·6	Jn.	——
Σ 1932	— Coronae Bor.	20	15 14·9	+27 7	5·6, 6·1	16·9	0·6	1921·7	Ph.	——
	γ Circini ...	...	15 16·8	−59 2	4·5, 4·8	66·2	1·0	1922·6	Jn.	——
	ε Lupi ...	...	15 17·2	−44 24	3·7, 6·7	276·2	1·4	1902	C.O.	——
Σ 1937	η Coronae Bor.	20	15 19·9	+30 34	5·2, 5·7	101·7	0·5	1921·6	Ph.	Test for nine-inch telescope. Binary. Period 42 years.
Σ 1938	μ² Boötis ...	20	15 21·5	+37 37	6·7, 7·3	47·1	1·6	1921·7	Ph.	Binary. Period, 235 years.
Σ 1950	— Coronae Bor.	20	15 26·5	+25 47	6·7, 8·2	92	3·4	...	...	Very little relative motion. Gold and blue.
	δ² Lupi ...	...	15 30·4	−44 41	4·8, 7·8	0·2	2·4	1922·6	Jn.	——
Σ 1954	δ Serpentis ...	32	15 31·0	+10 48	3·0, 4·0	185·2	4·1	1919·4	Gr.	——
OΣ 298	— Boötis ...	20	15 33·2	+40 4	7·0, 7·3	209·4	0·7	1922·6	Ph.	Binary. Period, 52 years.
Σ 1965	ζ Coronae Bor.	20	15 36·4	+36 54	4·1, 5·0	303	6·3	...	...	Scarcely any relative motion.
Rümk. 20	— Trianguli Aust.	...	15 40·5	−64 11	5·8, 5·8	151·1	2·1	1918·4	La P.	——
I 333	— Apodis ...	...	15 48·7	−77 47	6·5, 6·6	95·2	1·2	1897	C.O.	——

GEMINI. No. 16



ARTHUR COTTAM F.R.A.S. del. Epoch 1890.

Magnitudes 1 1·5 2 2·5 3 3·5 4 4·5 5 5·5 6 6·5 Telescopic

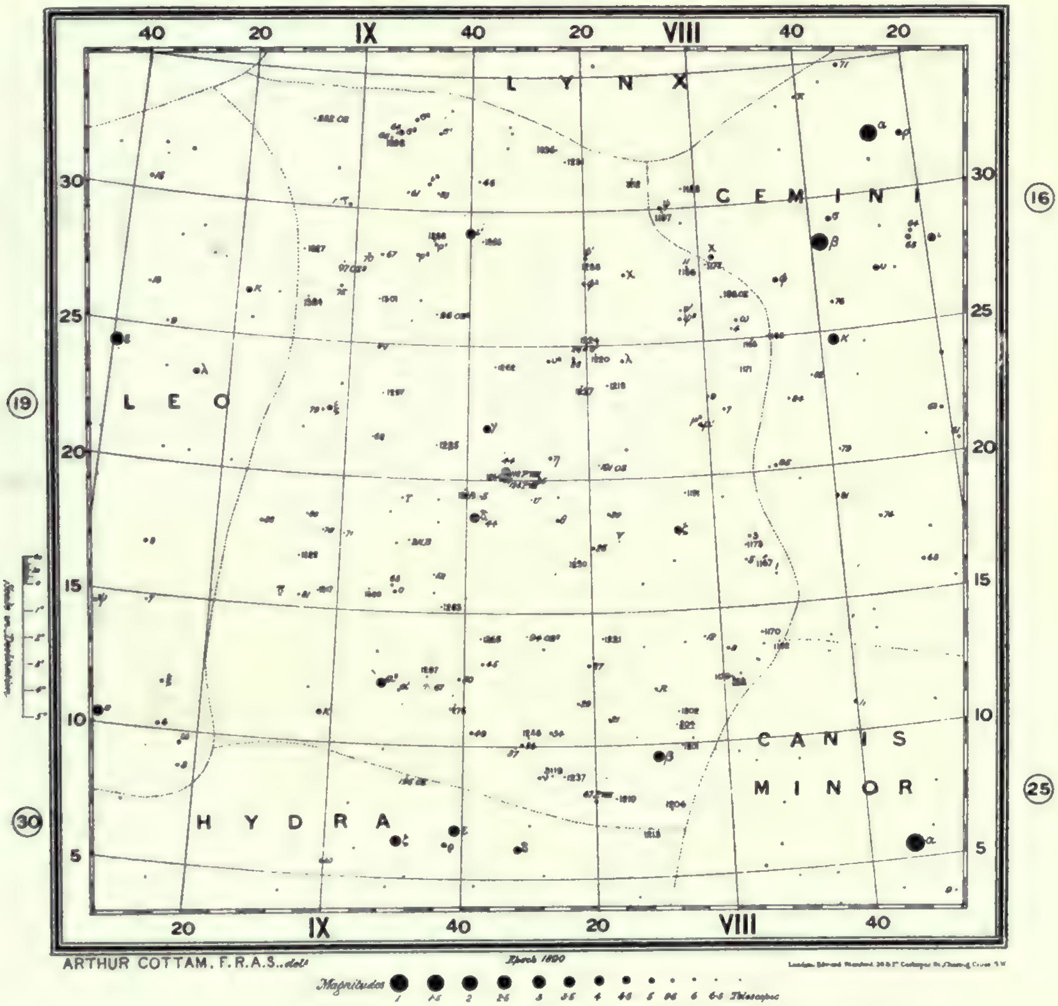
LIST OF DOUBLE STARS—*continued.*

Star and	Constellation.	Map.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
Dunlop196	ζ Lupi ...	...	15 51·8	−33 43	5·2, 5·5	48·8	10·6	1919·6	La P.	—
Dunlop197	η Lupi ...	...	15 54·8	−38 10	3·6, 7·7	20·7	15·2	1919·6	La P.	—
Σ 1998	ξ Scorpii ...	34	16 0·0	−11 10	4·9, 5·2	177·7	1·0	1921·5	Ait.	Binary. Period, 45 years. Third star about 7″ distant makes a triple system. Denoted as 1999 on Map.
	β Scorpii ...	34	16 0·8	−19 36	2·0, 4·0	24	13	...	...	Brighter star a close pair.
L 6706	...	...	16 4·4	−32 26	6·3, 7·0	85·2	7·8	1897	C.O.	—
β 120	ν Scorpii ...	34	16 7·3	−19 15	4·1, 7·0	337	41	...	...	Each component double as below.
	...	...	...	...	4·2, 6·7	9·2	0·9	1912·1	Gr.	—
	...	...	...	...	7·0, 8·0	48·4	2·1			
Σ 2021	49 Serpentis ...	32	16 9·6	+13 45	6·7, 6·9	337·7	3·7	1915	Franks	—
Σ 2032	σ Coronae Bor.	20	16 11·7	+34 1	5·0, 6·1	219·5	5·2	1921·4	Do.	Binary. Colour estimates discordant.
H*h*. 505	σ Scorpii ...	34	16 16·3	−25 24	3·0, 8·0	271·2	20·4	...	...	White and blue. Spectroscopic binary.
	— Scorpii ...	...	16 18·8	−33 1	6·5, 7·0	153·2	5·9	1907	C.O.	—
h 4850	— Scorpii ...	...	16 19·6	−29 31	6·5, 7·0	352	6·9	...	...	—
H*h* 512	ρ Ophiuchi ...	32	16 21·5	−23 19	6·0, 6·0	353·2	3·4	1905	Jouffray	In blank space. Binary.
Σ 2054	— Draconis ...	1	16 22·6	+61 51	5·7, 6·9	357·2	1·1	1900·6	Gr.	—
OΣ 312	η Draconis ...	1	16 22·9	+61 42	2·1, 8·1	141·7	5·3	1921·7	Ph.	Yellow and orange.
Antares	α Scorpii ...	34	16 24·5	−26 16	1·2, 7·0	276	3·7	...	...	Red and green.
Σ 2055	λ Ophiuchi ...	32	16 26·9	+ 2 10	4·0, 6·1	82·6	0·8	1922·0	Ph.	Binary. Period, 110 years.
Σ 2078	16 Draconis ...	1	16 34·3	+53 5	5·0, 6·0	112·0	3·5	1912	Gr.	—
L 6912	...	...	16 35·3	−48 37	5·6, 9·0	11·6	1·7	...	...	Fine multiple group.
Σ 2084	ζ Herculis ...	21	16 38·3	+31 42	3·0, 6·5	79·4	1·4	1921·6	Ait.	Binary. Period, 34 years.
OΣ 315	21 Ophiuchi ...	32	16 47·4	+ 1 22	6·2, 8·1	154·3	0·7	1907·2	Gr.	—
Σ 2107	— Herculis ...	21	16 48·7	+28 48	6·5, 8·0	31·2	0·6	1920·6	Ait.	Binary. Period, 154 years.
Σ 2114	— Ophiuchi ...	32	16 58·1	+ 8 34	6·2, 7·4	165·7	1·0	1921·5	Do.	—
Σ 2130	μ Draconis ...	1	17 3·7	+54 35	5·0, 5·1	130·4	2·2	1916·4	Ph.	Binary.
β 1118	η Ophiuchi ...	32	17 5·8	−15 38	3·1, 3·6	238·0	0·6	1921·5	Ait.	—
	36 Ophiuchi ...	32	17 10·5	−26 28	6·0, 6·0	190	4·2	1905	Doolittle	—
Σ 2140	α Herculis ...	21	17 11·0	+14 29	3·0, 6·1	111·3	4·6	1921·6	Ph.	Yellow and blue-green.
L 7194	— Arae ...	...	17 12·9	−46 33	5·6, 8·3	174·3	3·0	1922·6	Jn.	—
	39 Ophiuchi ...	32	17 13·1	−24 12	5·5, 6·0	356	11	...	...	Pale orange and clear blue.
Σ 2161	ρ Herculis ...	21	17 20·9	+37 13	4·0, 5·1	313·3	3·8	1921·7	Ph.	—
h 4949	— Arae ...	...	17 20·9	−45 46	5·6, 6·6	259·3	2·5	1922·6	Jn.	—
Σ 2173	— Ophiuchi ...	32	17 26·3	− 1 0	5·8, 6·1	147·3	0·8	1921·4	Ait.	Binary. Period, 46 years.
Σ 2202	61 Ophiuchi ...	32	17 40·6	+ 2 37	5·5, 5·8	93	20·6	...	...	No relative motion.
OΣ 338	— Ophiuchi ...	32	17 48·4	+15 20	6·6, 6·9	13·1	0·7	1919·6	Gr.	—
h 5003	— Sagittarii...	...	17 52·9	−30 15	6·0, 7·0	105	5	...	...	—
Σ 2264	95 Herculis ...	21	17 58·4	+21 36	4·9, 4·9	257·9	6·1	1921·6	Ph.	Fine pair. Very little relative motion. Strange colour variations recorded.
Σ 2262	τ Ophiuchi ...	32	17 58·7	− 8 11	5·0, 5·7	259·6	2·1	1913·4	Ph.	Binary. Period, 230 years.
h 5014	— CoronaeAust.	...	18 1·0	−43 26	5·0, 5·0	236·8	1·8	1910	C.O.	—
Σ 2272	70 Ophiuchi ...	32	18 1·4	+ 2 33	4·1, 6·1	127·9	5·7	1923·6	Ph.	Fine binary star. Period, 88 years.
Σ 2276	— Ophiuchi ...	32	18 2·0	+12 0	6·0, 7·0	258	6·8	...	...	No relative motion.
Σ 2281	73 Ophiuchi ...	32	18 5·8	+ 3 58	5·7, 7·2	72·9	0·6	1921·4	Ait.	Distance increasing. Binary. Periods of 220 and 423 years have been computed.
Σ 2289	— Herculis ...	21	18 6·6	+16 27	6·0, 7·1	228·2	1·1	1911·8	Gr.	—
	ξ Pavonis ...	...	18 15·9	−61 32	4·2, 8·2	150·1	3·3	1902	C.O.	Good colour contrast.
Σ 2306	— Scuti Sob.	32	18 17·7	−15 8	7·2, 7·9	220	11	...	...	The brighter star a close double.
Σ 2316	59 Serpentis ...	32	18 23·1	+ 0 8	5·5, 7·8	316	3·8	...	...	No relative motion.
OΣ 358	— Herculis ...	21	18 32·3	+16 55	6·8, 7·2	187·5	2·0	1919·6	Gr.	—
Σ 2375	— Serpentis ...	32	18 41·5	+ 5 24	6·2, 6·6	117·7	2·2	1905·6	Lau.	—
Σ 2382	ε¹ Lyrae ...	21	18 41·7	+39 35	4·6, 6·3	7·2	2·9	1921·6	Ph.	Binary.
Σ 2383	ε² Lyrae ...	21	18 41·7	+39 32	4·9, 5·2	116·8	2·3	1921·6	Ph.	Binary.
Σ 2379	5 Aquilae ...	33	18 42·3	− 1 3	5·6, 7·4	121	13	...	...	No relative motion.
Σ 2404	— Aquilae ...	33	18 47·0	+10 53	5·8, 7·0	182	3·7	...	...	Very little relative motion. Yellow and blue; remarkable colours.

List of Double Stars—*continued.*

Star and Constellation.		Map.	1920. R.A.	Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
Brisbane	— CoronaeAust.	...	18 55·6	−37 10	6·0, 6·2	282·5	12·3	1903	C.O.	——
Har. 150	ζ Sagittarii...	35	18 56·6	−30 0	4·0, 5·0	78·5	0·5	1921·5	Ait.	Now widening. Binary. Period, 22 years. Test for ten-inch telescope.
	γ CoronaeAust.	...	19 1·0	−37 10	4·3, 4·3	85·1	2·5	1922·6	Jn.	Binary. Period, 152 years.
Gale	— Pavonis ...	...	19 9·2	−66 48	5·6, 7·6	39·5	0·8	1901	C.O.	——
OΣ 371	— Lyrae ...	21	19 12·7	+27 19	6·8, 6·9	154	0·8	...	...	No relative motion.
Σ 2525	— Cygni ...	22	19 23·3	+27 10	7·4, 7·6	305·1	1·0	1921·7	Ait.	Binary. Period, 355 years.
	β Cygni ...	22	19 27·5	+27 47	3·0, 5·3	54·5	34·5	1916·8	Ph.	Little or no relative motion. Yellow and blue Very striking contrast. One of the most beautiful pairs in the sky.
Σ 2579	δ Cygni ...	22	19 42·5	+44 56	3·0, 7·9	276·4	1·9	1922·6	Ph.	Test for four-inch. Apt to be difficult in dark sky, because companion lies on diffraction ring. Binary. Period, 321 years.
Σ 2580	χ¹ Cygni ...	21	19 43·4	+33 33	5·1, 8·1	71	25·5	...	...	Yellow and blue. No relative motion.
Σ 2583	π Aquilae ...	33	19 44·9	+11 37	6·0, 6·8	113·2	1·6	1921·7	Ph.	Very little relative motion.
Σ 2603	ε Draconis ...	1	19 48·5	+70 4	4·0, 7·6	8·1	3·2	1921·6	Do.	——

CANCER. No 17



List of Double Stars—*continued.*

Star and Constellation.		Map.	1920. R.A.	1920. Dec.	Mags.	P.A.	Dist.	Date.	Observer	Remarks.
			h. m.	° ′		°	″			
Σ 2597	— Aquilae ...	33	19 51·0	— 6 57	6·9, 8·0	85·7	1·4	1900·9	Gr.	-
Σ 2605	ψ Cygni ...	22	19 53·6	+52 13	5·0, 7·5	182	3·4	...	...	Very little relative motion. Slight diminution in distance.
OΣ 395	16 Vulpeculae	23	19 58·6	+24 43	5·8, 6·2	105·1	0·8	1921·7	Ph.	- -
L 8337	— Indi ...	...	20 4·5	—57 46	6·5, 6·8	227·9	0·7	1901	C.O.	- -
Σ 2637	θ Sagittae ...	23	20 6·4	+20 43	6·0, 6·8	327	11·5	...	...	No relative motion. A distant companion of seventh magnitude.
	α Capricorni	36	20 13·6	—13 2	3·2, 4·2	291	376	...	...	Inserted as a naked-eye pair.
	κ² Sagittarii	...	20 18·4	—42 41	5·7, 7·7	195·1	1·4	1897	C.O.	——
Russ. 321	— Sagittarii...	...	20 21·7	—37 40	6·3, 8·5	83·4	1·3	1902	C.O.	Binary. Motion slow.
	ρ Capricorni	36	20 24·3	—18 5	5·7, 7·1	174	2·8	...	...	Pale yellow and ruddy purple.
Σ 2695	94 Vulpeculae	23	20 28·5	+25 32	6·2, 8·0	79·0	1·0	1913·6	Gr.	A binary.
β 151	β Delphini ...	23	20 33·8	+14 19	4·1, 5·4	347·8	0·6	1921·7	Lv.	Rapid binary.
Σ 2716	49 Cygni ...	22	20 37·8	+32 1	6·0, 8·1	49·1	2·6	1916·2	Gr.	Yellow and blue.
Σ 2727	γ Delphini ...	23	20 43·0	+15 51	4·0, 5·0	270	11	...	...	Gold and bluish-green.
OΣ 413	λ Cygni ...	22	20 44·3	+36 12	5·0, 6·2	47·9	0·6	1921·7	Ph.	Test for seven-inch telescope.
Rümk. 26	— Pavonis ...	...	20 45·0	—62 44	5·8, 5·8	93·9	2·4	1911	C.O.	——
Σ 2729	4 Aquarii ...	36	20 47·0	— 5 54	5·9, 7·2	336·2	0·6	1920·5	Ait.	Binary. Period, 152 years.
Σ 2735	— Aquarii ...	36	20 51·7	+ 4 13	6·2, 7·7	286·0	2·1	1905·7	Gr.	Very little relative motion.
Σ 2744	— Aquarii ...	36	20 59·0	+ 1 13	6·3, 7·0	157·6	1·3	1913·6	Ph.	——
Σ 2745	12 Aquarii ...	36	20 59·7	— 6 8	5·6, 7·7	190	2·7	...	...	Yellow and blue. No relative motion.
L 8625	...	...	21 0·9	—73 29	5·8, 6·1	134·4	8·4	1902	C.O.	——
Σ 2758	61 Cygni ...	22	21 3·3	+38 21	5·3, 5·9	132·2	24·1	1920·7	Ph.	The first stellar system to have its parallax determined (1838). Probably a physical pair.
	θ Indi ...	...	21 14·2	—53 47	4·6, 7·1	281·5	4·8	1911	C.O.	- -
OΣ 437	— Cygni ...	22	21 17·5	+32 7	6·5, 7·2	39·3	1·8	1912·3	Gr.	-
	θ¹ Microscopii	...	21 19·3	—41 21	5·9, 6·2	292·3	1·0	1900	C.O.	-
Mel. 6	— Microscopii	...	21 21·9	—42 54	5·6, 7·7	145·8	2·9	1900	C.O.	- -
Σ 2799	— Pegasi ...	11	21 25·6	+10 44	6·6, 6·6	288·7	1·5	1921·6	Do.	Probably a slow binary.
Σ 2804	— Pegasi ...	11	21 29·3	+20 21	7·3, 8·0	338·5	3·1	1921·6	Do.	Little relative motion.
h 5278	λ Octantis ...	...	21 38·9	—83 6	5·4, 7·5	71·7	3·2	1918·8	La P.	——
Σ 2822	μ Cygni ...	22	21 40·5	+28 23	4·0, 5·0	136·4	1·4	1921·7	Ph.	Probably a binary. Yellow and blue.
Σ 2863	ξ Cephei ...	2	22 1·4	+64 14	4·7, 6·7	281·1	7·0	1921·6	Do.	Little relative motion. Probably a slow binary. Yellow and blue.
Σ 2878	— Pegasi ...	11	22 10·5	+ 7 35	6·5, 8·0	124·5	1·2	1902·5	Gr.	A slow binary.
Σ 2894	— Lacertae ...	6	22 15·4	+37 22	6·0, 8·2	193	15·3	...	...	No relative motion. White and blue.
β 172	51 Aquarii ...	36	22 19·9	— 5 15	5·6, 5·7	349·6	0·6	1921·6	Ait.	-
Σ 2902	— Lacertae ...	6	22 20·2	+44 57	7·1, 8·0	89	6·3	...	...	No relative motion.
South 345	53 Aquarii ...	36	22 22·3	—17 8	6·0, 6·5	308·0	6·2	1911·8	Gr.	
	δ Toucani ...	...	22 21·7	—65 22	4·8, 8·1	281·6	6·8	1899	C.O.	
Σ 2909	ζ Aquarii ...	36	22 24·7	— 0 26	4·0, 4·1	303·8	2·8	1921·9	Lv.	Very fine pair. Slow binary.
Σ 2922	8 Lacertae ...	6	22 32·3	+39 13	6·0, 6·5	185·5	22	...	...	Fine multiple system.
OΣ 483	52 Pegasi ...	11	22 55·2	+11 18	6·2, 7·7	238·3	0·9	1922·6	Ph.	-
	θ Gruis ...	...	23 2·4	—43 58	4·4, 7·4	40·5	1·9	1920·8	La P.	
Dunlop246	— Gruis ...	...	23 2·6	—51 8	6·1, 6·6	257·6	8·0	1909	C.O.	
Σ 2978	— Pegasi ...	11	23 3·6	+32 24	6·8, 8·0	146	8·4	...	...	No relative motion.
Σ 2998	94 Aquarii ...	36	23 14·9	—13 54	5·2, 7·2	347	13·5	...	...	Yellowish white and blue. No relative motion.
OΣ 500	— Andromedae	10	23 33·6	+43 59	6·1, 7·0	333·0	0·6	1922·8	Ait.	-
	θ Phoenicis...	...	23 35·2	—47 5	6·3, 6·9	271·2	4·1	1909	C.O.	——
A.G.Clark 14	78 Pegasi ...	11	23 40·0	+28 58	5·0, 8·1	200·1	1·5	1911·3	Gr.	
β 995	— Andromedae	10	23 43·6	+46 23	6·5, 8·5	239·7	0·8	1922·8	Ait.	
Σ 3042	— Andromedae	10	23 47·8	+37 27	7·0, 7·0	87·2	4·9	1906·8	Gr.	Little relative motion.
Σ 3044	— Pegasi ...	11	23 48·9	+11 29	6·9, 7·3	282	18·9	1905·0	Gr.	Variation in magnitudes reported.
Σ 3050	— Andromedae	10	23 55·4	+33 17	6·0, 6·0	227·9	2·0	1922·6	Ph.	A binary.

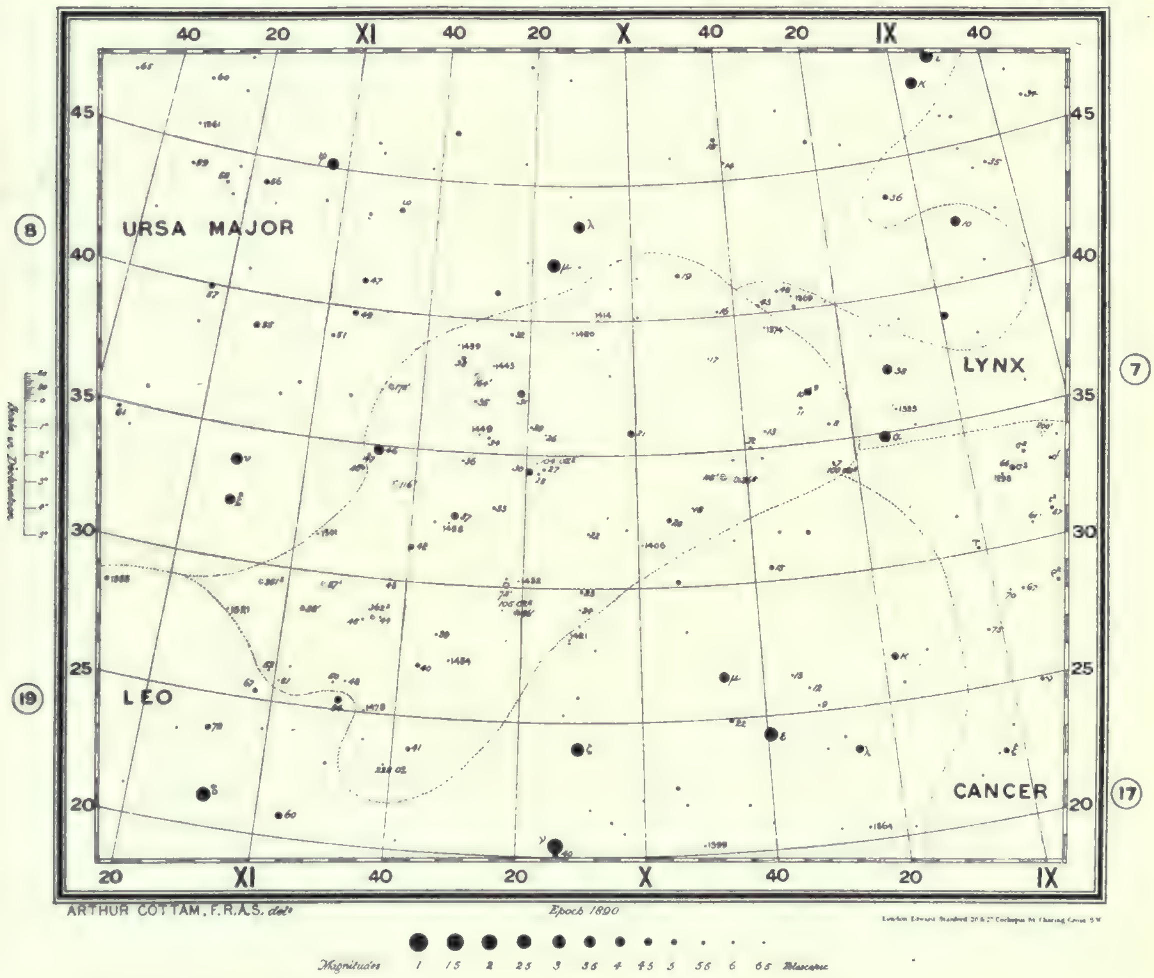
PART III.

ASTRONOMICAL SYMBOLS AND TABLES.

Signs of Zodiac.

	Longitude.		Longitude.
	° °		° °
♈ Aries	0– 30	♎ Libra	180–210
♉ Taurus	30– 60	♏ Scorpio	210–240
♊ Gemini	60– 90	♐ Sagittarius	240–270
♋ Cancer	90–120	♑ Capricornus	270–300
♌ Leo	120–150	♒ Aquarius	300–330
♍ Virgo	150–180	♓ Pisces	330–360

LEO MINOR. Nº 18



Planets.

☉ Sun.	♂ Mars.	① Ceres.
☽ Moon.	♃ Jupiter.	② Pallas,
☿ Mercury.	♄ Saturn.	etc.
♀ Venus.	♅ or ⛢ Uranus.	☄ Comet.
♁ or ⊕ Earth.	♆ Neptune.	

Orbits, etc.

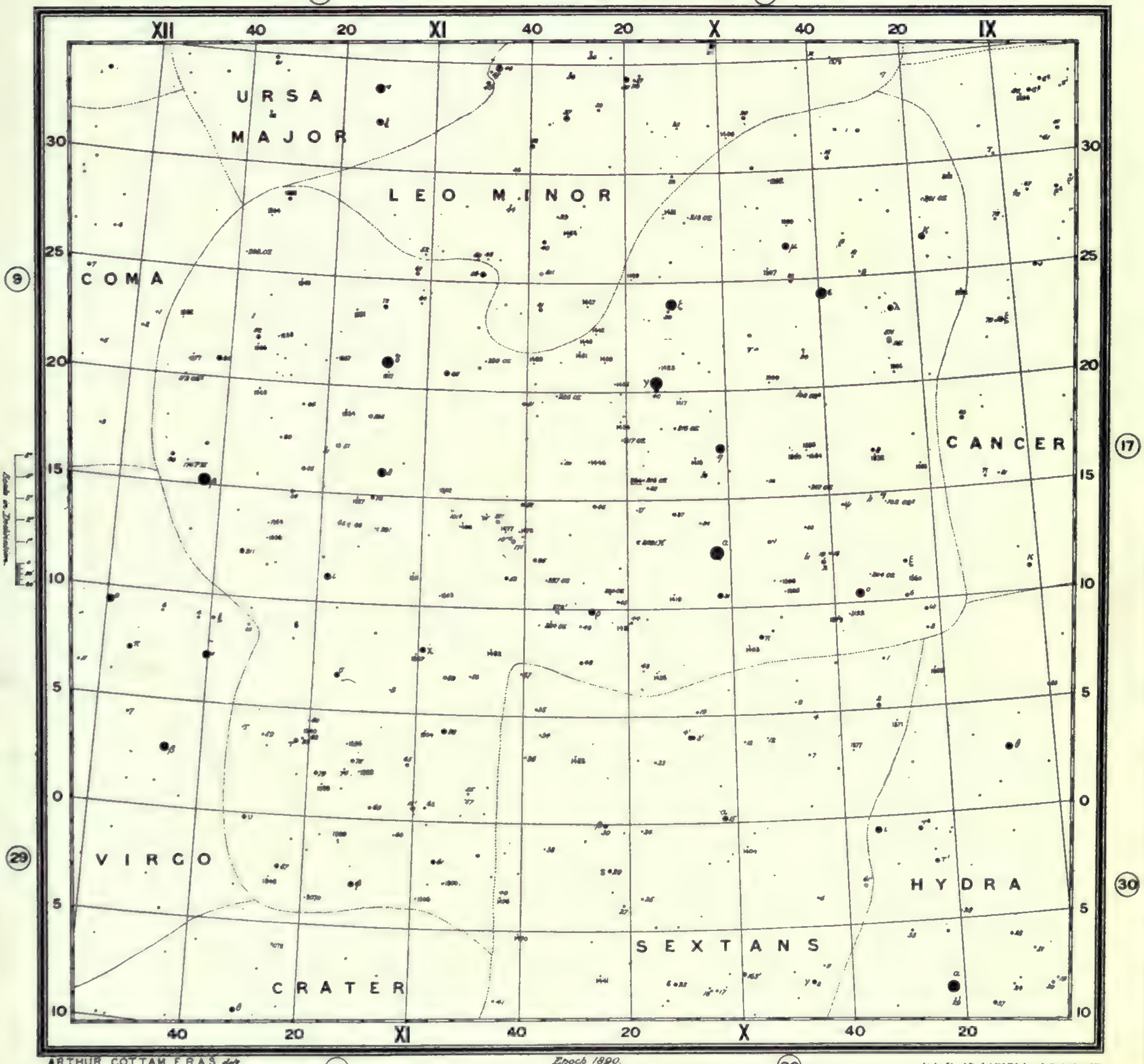
☌ Conjunction.
☍ Opposition.
□ Quadrature.
☊ Ascending Node.
☋ Descending Node.
π or ϖ Longitude of Perihelion.
π or Π Parallax.
ω Arc from Node to Perihelion.
i Inclination to Ecliptic.
q Distance from Sun at Perihelion.
a Semi-major axis.
b Semi-minor axis.
e Eccentricity.
ϕ Angle whose sine = eccentricity.
μ or n Mean daily motion.
P Period of Revolution.
T Time of Perihelion passage.
E Epoch of Osculation, *i.e.*, the time at which the elements have the assigned values.
v or θ True anomaly.
M Mean anomaly.
u or E Eccentric anomaly.
m Mass or Magnitude.
Æ or R.A. or α Right Ascension.
Decl. or δ Declination.
N.P.D. North Polar Distance.
E N.P.D. Ecliptic North Polar Distance.
Z.D. Zenith Distance.
L or λ Longitude.
β Latitude (celestial).
ϕ ,, (terrestrial) Geographical.
ϕ' ,, (,,) Geocentric.
ρ Density.
R, r Distance from Sun of Earth and other body respectively.
Δ (sometimes ρ) Distance from Earth.
ε Obliquity of Ecliptic.
X, Y, Z. Rectangular co-ordinates of Sun from Earth.
The axes run: (1) to First Point of Aries; (2) to point in Equator whose R.A. is 6 hours; (3) to North Pole of Equator.
x, y, z. Heliocentric rectangular co-ordinates of a body.
ξ, η, ζ, Geocentric rectangular co-ordinates of a body.

All distances in the Solar System are measured (unless the contrary is stated) in units of the mean distance of the Earth from the Sun.

THE GREEK ALPHABET.

α	*Alpha*	η	*Ēta*	ν	*Nu*	τ	*Tau*
β	*Bēta*	θ	*Thēta*	ξ	*Xi*	υ	*Upsilon*
γ	*Gamma*	ι	*Iōta*	ο	*Omicron*	φ	*Phi*
δ	*Delta*	κ	*Kappa*	π	*Pi*	χ	*Chi*
ε	*Epsīlon*	λ	*Lambda*	ρ	*Rho*	ψ	*Psi*
ζ	*Zēta*	μ	*Mu*	σ	*Sigma*	ω	*Omega*

LEO. No. 19



ARTHUR COTTAM, F.R.A.S. delt

Epoch 1890.

Magnitudes 1 1·5 2 2·5 3 3·5 4 4·5 5 5·5 6 6·5 Telescopic

Astronomical Constants.

Solar Parallax ... $8''\cdot80$

Constant of Aberration ... $20''\cdot47$

Moon's Equatorial Horizontal Parallax ... $3422''\cdot70$

Obliquity of Ecliptic ... $23^\circ\ 27'\ 8''\cdot26 - 0''\cdot4684\ (t - 1900)$

Mean distance Earth to Sun ... = 1 astronomical unit
= 149,500,000 km. = 92,900,000 miles.

Mean distance Earth to Moon 384,400 km. = 238,860 miles = 60·267 radii of the Earth.

Velocity of light in vacuo ... 299,860 km. = 186,325 miles per second.

Light travels unit distance in ... 498·58*s*. = 8·310*m*.

Length of the year:

	d.	d.	h.	m.	s.
Tropical (Equinox to Equinox) ...	365·242190 =	365	5	48	46·0
Sidereal ...	365·256360 =	365	6	9	9·5
Anomalistic (Perihelion to Perihelion) ...	365·259642 =	365	6	13	53·1

Length of the month:

Synodical (New Moon to New Moon) ...	29·530588 =	29	12	44	2·8
Tropical (Equinox to Equinox) ...	27·321582 =	27	7	43	4·7
Sidereal ...	27·321661 =	27	7	43	11·5
Anomalistic (Perigee to Perigee) ...	27·554550 =	27	13	18	33·1
Nodical (Node to Node) ...	27·212220 =	27	5	5	35·8

Length of the day:

Sidereal = 0·99726957 mean solar days = 23*h*. 56*m*. 4·091*s*. mean solar time.

Mean Solar = 1·00273791 sidereal days = 24*h*. 3*m*. 56·555*s*. sidereal time.

Earth's mean orbital speed ... 29·766 km. = 18·496 miles per sec.

Mean density of the Earth ... = 5·53 (water = 1).

Dimensions of the Earth: (Hayford's Spheroid, 1909)

Equatorial Radius ... a = 6378·388 km. = 3963·34 miles.

Polar Radius ... b = 6356·909 km. = 3949·99 miles.

Flattening or ellipticity ... $\frac{a-b}{a} = \frac{1}{297\cdot0}$

North Pole of Galactic Plane, including branch ... R.A. 12*h*. 44*m*. Dec. 26°·8 N.

Vertex of Star-streaming ... R.A. 90° Dec. 12° N.

Solar Apex ... R.A. 270° Dec. 34° N.

Solar Motion ... 19·5 km. = 12·1 miles per second.

Sun's Stellar Magnitude ... − 26·7*m*.

Sun's Absolute Magnitude (at distance of 10 parsecs) ... 4·9*m*.

Light ratio for one magnitude ... 2·512 ... Log ratio 0·4000

Light year ... $9\cdot463 \times 10^{12}$ km. = $5\cdot880 \times 10^{12}$ miles
= 63290 astronomical units = 0·3069 parsecs.

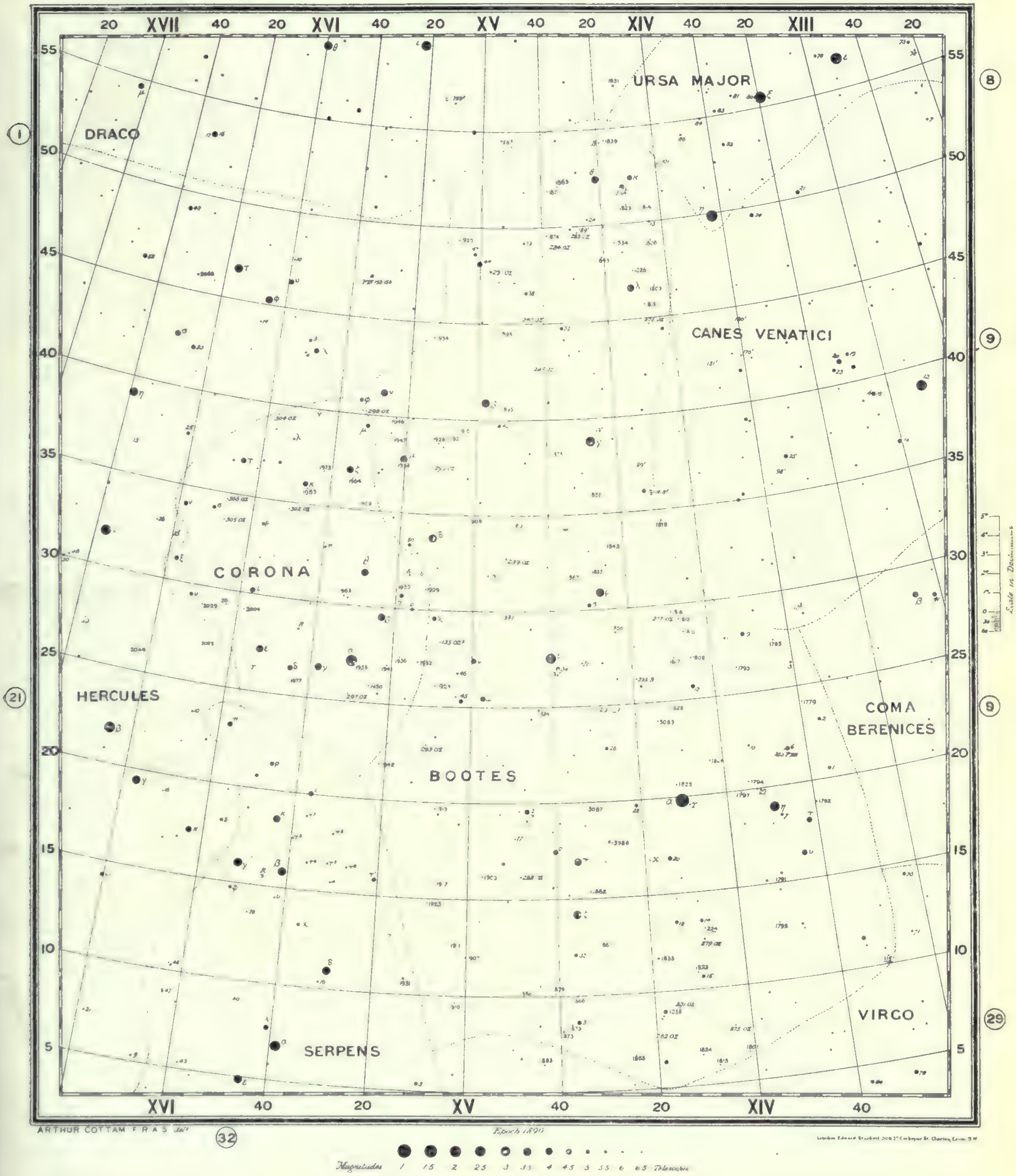
Parsec ... $30\cdot84 \times 10^{12}$ km. = $19\cdot16 \times 10^{12}$ miles
= 206265 astronomical units = 3·259 light years.

Number of stars in the sky: (Chapman and Melotte)

	phot. mag.	Number		phot. mag.	Number
Brighter than phot. mag.	5·0	689	Brighter than phot. mag.	10·0	271,800
	6·0	2,715		11·0	698,000
	7·0	9,810		12·0	1,659,000
	8·0	32,360		13·0	3,682,000
	9·0	97,400		14·0	7,646,000

Number of square degrees in the sky ... 41,253

BOOTES & CORONA BOREALIS. Nº 20.



Dimensions of Sun, Moon and Planets.

Name.	Semidiameter at mean Dist-ance.	Semidiameter at mean Opp'sit'n distance.	Diameter in Kilo-metres.	Diameter in Miles.	Mass. ☉ = 1	Mass. ⊕ = 1	Density. ⊕ = 1	Density. Water = 1	Volume ⊕ = 1	Surface gravity ⊕ = 1
	″	″			1 :					
Sun	959·63	- -	1391000	864000	—	333432	0·26	1·42	1300000	28·0
Moon	932·58	-	3476	2160	27158000	0·0123	0·60	3·34	0·0203	0·16
Mercury	3·34	5·45	4800	3000	9000000	0·037	0·68	3·73	0·055	0·2
Venus	8·41	30·40	12200	7600	403490	0·826	0·94	5·21	0·876	0·90
Earth (Eq'l.) ...	8·80	-- -	12757	7927	329390	1·000	1·00	5·53	1·000	1·00
Earth (Polar) ...	8·77	—	12714	7900						1·00
Mars	3·07	8·94	6800	4200	3093500	0·108	0·71	3·95	0·151	0·38
Jupiter (Eq'l.) ...	18·93	23·43	142700	88700	1047·35	318·4	0·24	1·34	1312	2·64
Jupiter (Polar) ...	17·67	21·87	133200	82800						2·67
Saturn (Eq'l.) ...	8·72	9·76	120800	75100	3501·6	95·2	0·12	0·69	763	1·13
Saturn (Polar) ...	7·81	8·73	108100	67200						1·15
Uranus	1·78	1·88	49700	30900	22869	14·6	0·25	1·36	59	0·96
Neptune ...	1·21	1·26	53000	33000	19314	16·9	0·24	1·30	72	0·98

Fixed Elements of the Planetary Orbits.

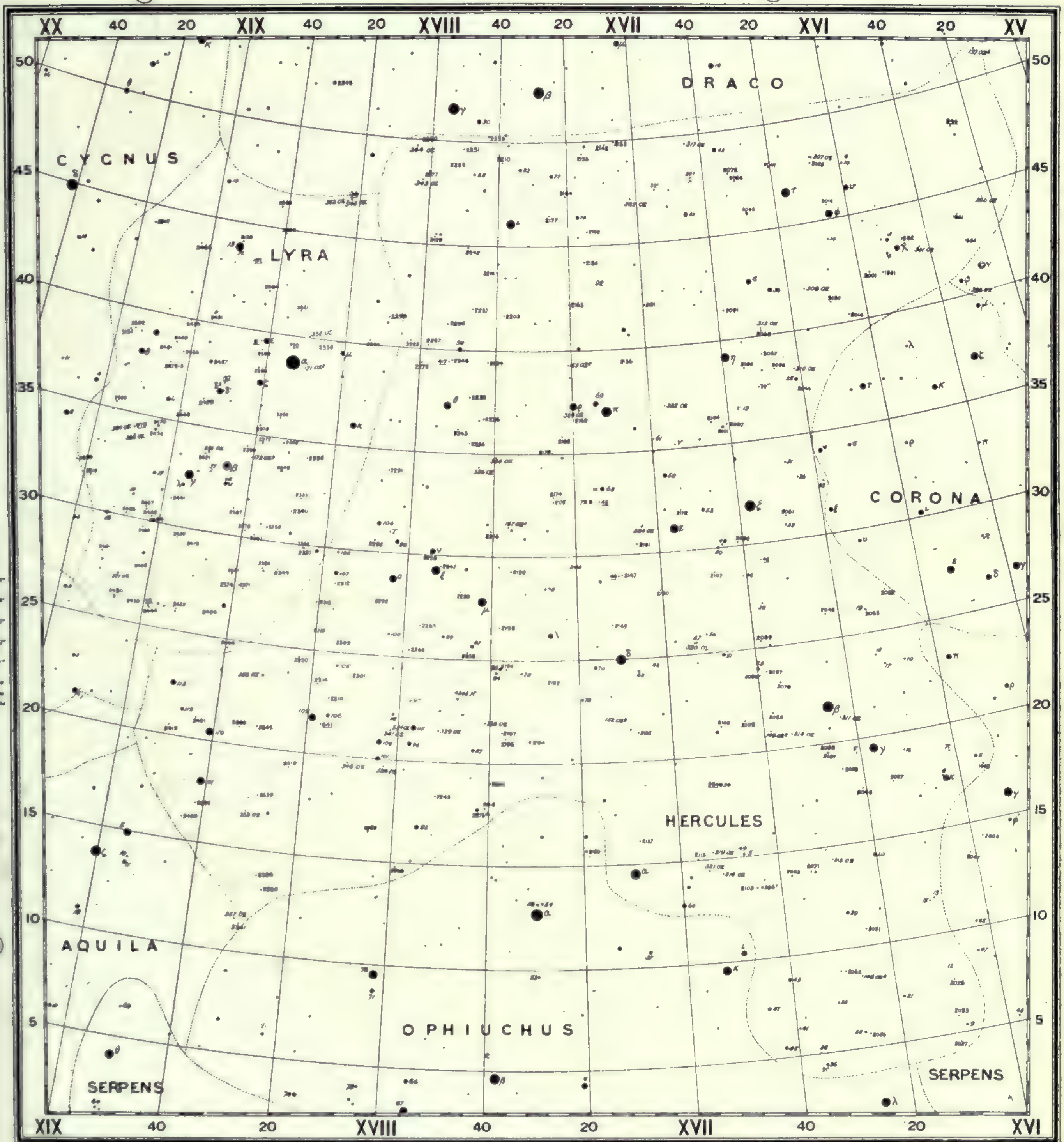
Name.	Mean Distance. Astronom-ical Units.	Mean Distance. Millions of Miles.	Sidereal Period in Tropical Years.	Sidereal Mean Daily Motion.	Synodic Period in Days.	Period of Axial Rotation.
				″		
☿ Mercury	0·387099	36·0	0·2408	14732·420	115·88	88*d.* (?)
♀ Venus	0·723331	67·2	0·6152	5767·670	583·92	225*d.* (?)
♁ Earth	1·000000	92·9	1·0000	3548·193	—	23*h.* 56*m.* 4·100*s.*
♂ Mars	1·523688	141·5	1·8809	1886·519	779·94	24*h.* 37*m.* 22·65*s.*
♃ Jupiter	5·202803	483·3	11·8622	299·128	398·88	9*h.* 50·5*m.* ± — 9*h.* 55·7*m.* ± (*see* Chapter VIII)
♄ Saturn	9·538843	886·1	29·4577	120·455	378·09	10*h.*14*m.*24*s.*(*Eq'l*)
♅ Uranus	19·190978	1782·8	84·0153	42·23	369·66	About 10¾*h.*
♆ Neptune	30·070672	2793·5	164·7883	21·53	367·49	About 7¾*h.*

Elements for the Epoch 1922 January 0·0.

Name.	Eccentricity.	Inclination to the Ecliptic. °	′	″	Mean Longitude of the Ascending Node. °	′	″	Mean Longitude of the Perihelion. °	′	″	Mean Longitude at the Epoch. °	′	″
☿ Mercury	0·205619	7	0	12	47	24	24	76	14	31	300	25	42·5
♀ Venus	0·006810	3	23	38	75	58	39	130	28	25	256	11	33·4
♁ Earth	0·016742		—			—		101	35	57	99	22	22·9
♂ Mars	0·093333	1	51	1	48	57	22	334	37	23	184	39	34·0
♃ Jupiter	0·048374	1	18	27	99	39	37	13	3	57	185	59	41·2
♄ Saturn	0·055814	2	29	29	112	58	32	91	31	11	175	43	13·8
♅ Uranus	0·047106	0	46	22	73	36	3	169	24	3	337	56	6·7
♆ Neptune	0·008547	1	46	38	130	55	15	43	56	53	133	23	32·1

LYRA & HERCULES

(22) (1) No. 21.



(20) (33)

ARTHUR COTTAM, F.R.A.S. delt. Epoch 1890.

(32)

Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 Telescopic

RADIANT-POINT AND AVERAGE NUMBER (n) OF VISIBLE METEORS FOR EVERY NIGHT IN THE YEAR.

By W. F. DENNING, F.R.A.S.

Day of Month.	January. Radiant. α δ ° °	n	February. Radiant. α δ ° °	n	March. Radiant. α δ ° °	n	April. Radiant. α δ ° °	n	May. Radiant. α δ ° °	n	June. Radiant. α δ ° °	n
1	230 + 52	10	131 + 32	7	166 + 5†	7	130 + 30	8	200 + 7	7	350 + 38	8
2	230 + 52*	18	211 + 69	8	176 + 9	7	140 + 50	7	332 − 3	7	252 − 10	6
3	230 + 52*	28	120 − 7	7	167 + 4	6	236 + 9	8	333 − 2†	6	228 − 7	5
4	230 + 52	12	61 + 28	7	116 + 47	7	203 + 57	8	334 − 2*	6	330 + 27	6
5	230 + 52	9	60 + 35	6	51 + 43	8	238 + 5	7	336 − 2†	7	285 + 32	6
6	230 + 52	10	130 + 46	6	17 + 6	7	280 + 58	7	337 − 2†	6	230 + 34	7
7	325 + 4	9	210 − 28	6	270 + 47	6	210 − 10	8	338 − 2	5	252 − 23	6
8	329 + 60	8	32 + 9	7	104 + 34	7	209 − 9	6	234 + 9	5	274 + 1	6
9	230 + 52	7	47 + 46	7	100 0	7	19 + 57	7	207 − 10	6	273 − 3	6
10	43 + 22	7	147 − 12	7	240 + 63	7	197 + 71	7	246 0	6	241 + 48	7
11	220 + 13	7	75 + 41	6	213 + 53	8	236 + 8	8	284 + 47	6	311 + 62	6
12	154 − 10	8	130 + 21	6	218 + 12	8	210 − 9	8	234 + 11	6	252 + 12	6
13	230 + 52	8	201 + 57	7	133 + 31	7	1[illegible]9 + 9	7	237 − 16	6	274 + 22	7
14	129 + 44	8	105 + 51	7	270 + 48	8	173 + 45	7	313 + 15	7	262 − 12	6
15	120 − 3	9	135 + 78	7	250 + 54	9	311 + 61	8	294 0	6	282 − 13	6
16	119 0	8	155 + 40	8	134 + 39	8	219 + 78	7	296 0	6	270 + 47	7
17	295 + 53	9	72 + 43	8	315 + 46	9	262 + 62	6	330 + 50	5	252 + 11	7
18	111 + 23	9	55 + 82	8	316 + 78	10	267 + 33	6	231 + 27	5	262 + 62	8
19	191 + 72	9	176 + 47	8	161 + 57	9	268 + 33	7	252 − 20	5	263 − 12	7
20	213 + 53	9	263 + 36	9	203 + 57	8	270 + 33*	8	302 + 20	6	333 + 27	6
21	220 + 9	10	181 + 36	9	161 + 57	8	271 + 33*	9	252 + 11	6	282 − 26	8
22	143 + 38	9	155 + 14	9	105 + 52	7	272 + 33	10	283 − 13	6	261 + 3	8
23	159 + 27	8	262 + 63	8	190 + 20	7	273 + 33	8	331 + 72	7	260 + 36	6
24	143 + 38	7	75 + 42	8	161 + 58	8	275 + 33	7	246 + 29†	7	238 + 47	7
25	331 + 56	6	117 + 47	8	175 + 20	8	276 + 33	6	278 + 31	6	24 + 43†	7
26	261 + 63	6	160 + 59	8	208 − 10	8	278 + 33	6	194 + 58	6	352 + 39	7
27	220 + 13	7	165 + 5	7	229 + 32	7	121 + 28	5	273 + 22	6	213 + 53*	7
28	122 + 29	7	150 − 11	7	263 + 62	7	200 + 7	6	310 + 61	5	228 + 58*	7
29	213 + 52†	8	—		316 + 76	8	190 + 59	5	240 + 46	6	245 + 64	6
30	156 + 42	7	—		220 + 40	8	291 + 59†	6	330 + 28	6	303 + 24	6
31	194 + 57	8	—		260 + 61	9	—		311 + 80	7	—	

Day of Month.	July. Radiant. α δ ° °	n	August. Radiant. α δ ° °	n	September. Radiant. α δ ° °	n	October. Radiant. α δ ° °	n	November. Radiant. α δ ° °	n	December. Radiant. α δ ° °	n
1	270 + 30	7	33 + 55	21	240 + 70	16	355 + 40	15	43 + 22†	14	44 + 56	12
2	294 + 39	8	34 + 55	20	304 + 51†	15	230 + 52	13	58 + 9†	12	100 + 33	9
3	43 + 36	7	35 + 55	19	74 + 41	14	133 + 79	14	61 + 35	12	101 + 33	9
4	316 + 46	8	36 + 56	19	346 + 1	13	310 + 79	14	61 + 35	13	102 + 33	10
5	11 + 48	9	38 + 56	21	350 + 42	12	98 + 43	14	61 + 35	14	103 + 33	11
6	282 − 13	9	39 + 56	22	61 + 36	12	316 + 59	12	61 + 35	12	104 + 33	12
7	294 + 39	8	40 + 56	24	73 + 4	14	31 + 18	13	77 + 31	13	106 + 33	13
8	310 + 78	8	42 + 57	27	291 + 29	13	77 + 31†	12	58 + 16	13	107 + 33	12
9	343 + 12	9	43 + 57	34	348 + 2	12	100 + 13	14	105 + 51	14	108 + 33	14
10	284 − 13	9	44 + 57*	48	74 + 41†	12	35 − 10	13	59 + 18	14	110 + 33	16
11	319 + 22	10	45 + 57*	69	330 + 71	13	13 + 6	14	108 + 11	15	111 + 33*	22
12	7 + 37	10	47 + 57	48	316 + 48	12	42 + 55	14	43 + 21	16	112 + 33*	23
13	317 + 31†	11	48 + 57	30	13 + 5	13	163 + 59	15	150 + 22	17	113 + 32	19
14	314 + 47	11	50 + 58	22	290 + 52	14	133 + 68	16	150 + 22*	20	114 + 32	16
15	15 + 49	12	51 + 58	20	61 + 35	15	31 + 9†	17	150 + 22*	21	116 + 32	13
16	16 + 49	12	52 + 58	18	61 + 36	15	92 + 15	21	150 + 22	18	192 + 70	10
17	17 + 50	13	54 + 58	17	4 − 2	15	92 + 15	20	25 + 43	17	133 + 48	10
18	18 + 50	13	55 + 58	16	46 + 42	14	92 + 15	21	25 + 43	16	230 + 33	9
19	19 + 51	14	56 + 59	15	75 + 15	13	92 + 15*	21	25 + 43*	15	194 + 67	8
20	20 + 51	15	297 0	15	272 + 23	14	98 + 14*	20	25 + 43	14	220 + 76	9
21	21 + 51	16	291 + 60	16	31 + 19†	15	92 + 15	19	63 + 22†	15	161 + 59	8
22	22 + 51	17	291 + 60	17	74 + 42	17	98 + 14	18	63 + 22	16	194 + 67	10
23	23 + 52	18	291 + 60	19	63 + 23	16	42 + 21	17	63 + 22	15	194 + 33	10
24	24 + 52	19	60 + 50	19	192 + 68	15	98 + 14	16	145 + 8	16	218 + 36	8
25	25 + 53	20	5 + 11	20	98 + 42†	14	92 + 15	16	155 + 39	14	167 + 32	8
26	26 + 53	21	320 + 11	21	87 + 42	13	60 − 10	15	161 + 58	15	47 + 65	9
27	27 + 53	23	75 + 33	20	4 + 28†	14	99 − 16	14	64 + 22	14	177 + 49	8
28	28 + 54	25	26 + 62	19	75 + 15	15	44 + 5†	15	64 + 22	15	115 + 32	9
29	29 + 54	27	106 + 52	20	348 + 2	13	109 + 23	16	81 + 23	14	77 + 32	9
30	30 + 54	26	262 + 63	19	13 + 6†	14	26 + 72	15	190 + 58	13	230 + 52	10
31	32 + 54	23	2 − 2	18	—		43 + 22	14	—		230 + 52	9

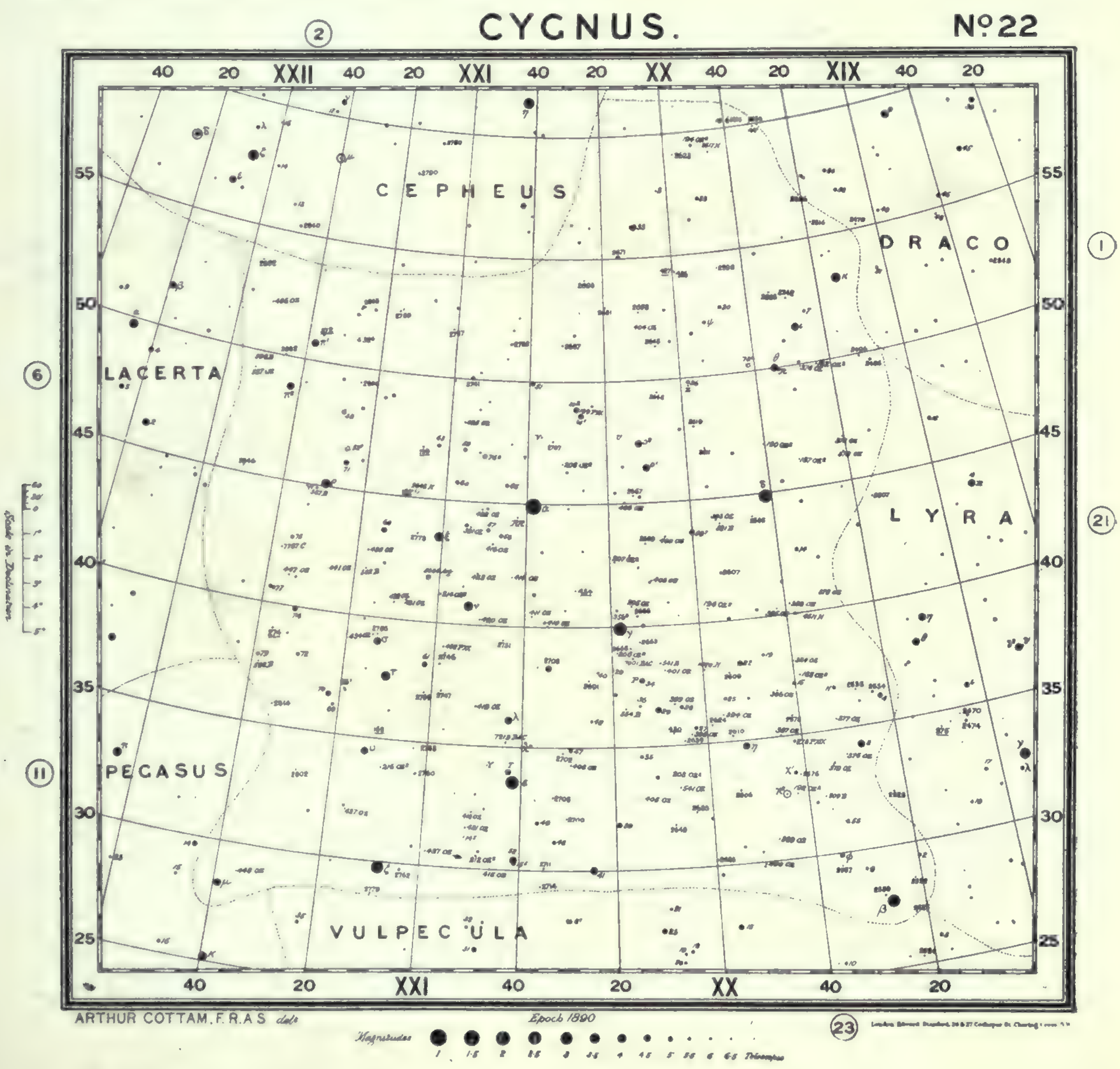
* Special showers. † Probable good displays. n = Average hourly number of meteors visible from all the active showers, to any one observer, on a clear moonless night.

PULKOVO MEAN REFRACTIONS.

Bar., 29·5 in. Attached and External Thermometers, 50° F.

App. Alt.	Mean Refraction.	App. Alt.	Mean Refraction.	App. Alt.	Mean Refraction.	App. Alt.	Mean Refraction.	App. Alt.	Mean Refraction.
°	′ ″	°	′ ″	°	′ ″	°	′ ″	°	″
0	33 51	10	5 13	20	2 36	30	1 39	45	57
1	23 53	11	4 46	21	2 28	31	1 35	50	48
2	17 55	12	4 23	22	2 21	32	1 31	55	40
3	14 7	13	4 3	23	2 14	33	1 28	60	33
4	11 31	14	3 45	24	2 8	34	1 25	65	27
5	9 40	15	3 30	25	2 2	36	1 19	70	21
6	8 19	16	3 17	26	1 57	38	1 13	75	15
7	7 15	17	3 5	27	1 52	40	1 8	80	10
8	6 26	18	2 54	28	1 47	42	1 3	85	5
9	5 46	19	2 44	29	1 43	44	0 59	90	0

The above table shows the amounts by which the apparent altitude of a star is increased by the bending of its light in the Earth's atmosphere. The effect is greatest on the horizon (*i.e.*, altitude 0°) and is zero at the zenith. When a star is on the meridian, refraction affects only its Declination. Thus, for instance, in latitude 52° N., where the altitude of a star on the equator is 38°, we see from the table that its apparent altitude is increased by 1′ 13″, and the Declination Circle of a perfectly adjusted equatorial should indicate this excess over the true Declination when the star is central in the field, and is crossing the meridian.



THE IMPORTANT ECLIPSES OF THE NEXT 50 YEARS, 1925 TO 1974.

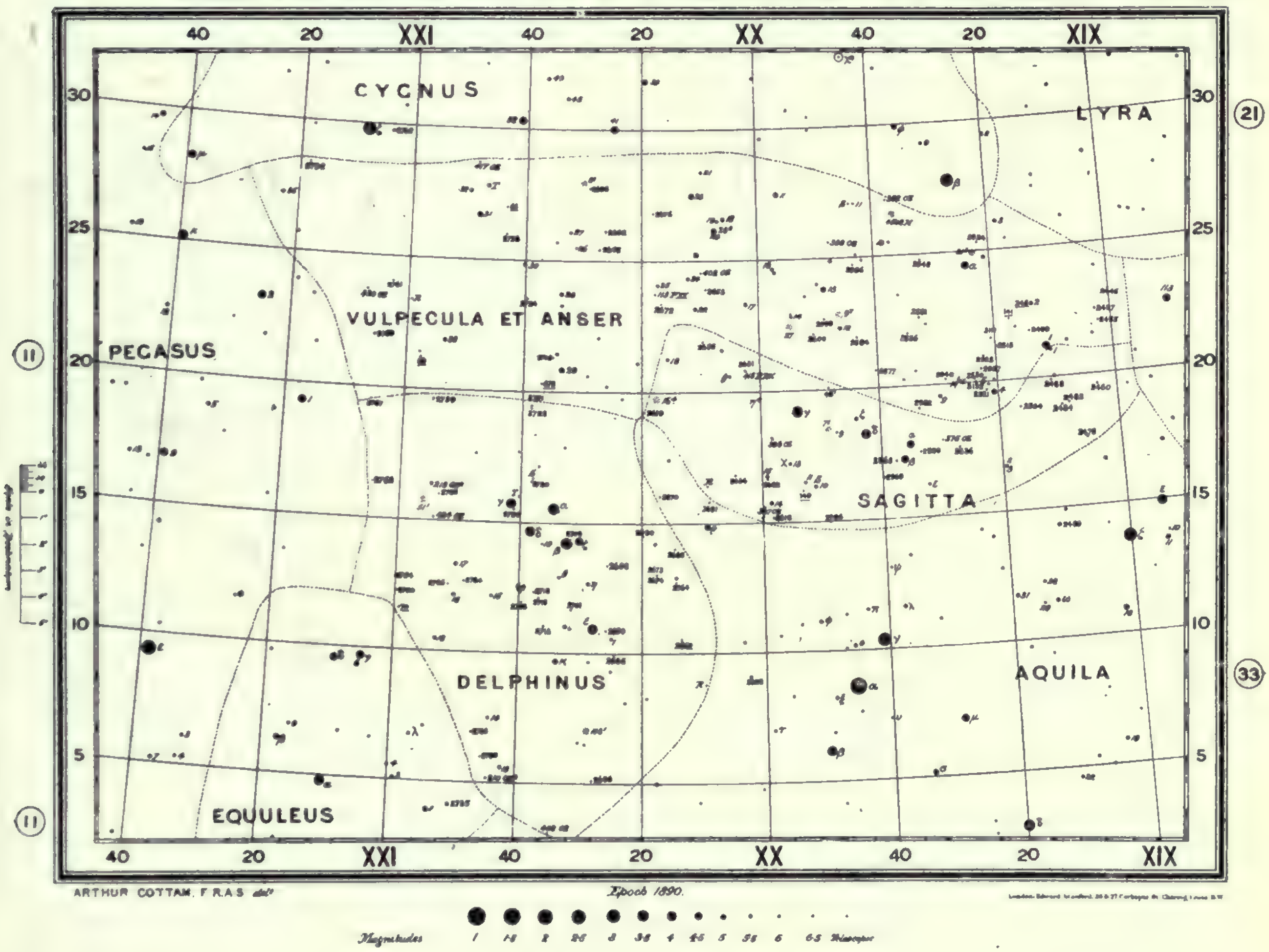
All eclipses visible in the British Isles are included, and the more important of those of Sun visible elsewhere. G.B. stands for Great Britain.

Body Eclipsed.	Total or Partial.	Date	Approximate Greenwich Time.	Description.
Sun	Total	1925, Jan. 24	4 p.m.	Total in N.E. portion of U.S.A. Almost total in Hebrides. Large throughout G.B. about sunset.
Moon	Partial	,, Feb. 8	10 p.m.	$\frac{3}{4}$ eclipsed. Visible G.B.
Sun	Total	1926, Jan. 14	6 a.m.	Total Amirante Islands, Sumatra, Borneo. Invisible G.B.
Moon	Total	1927, June 15	8 p.m.	Latter portion visible G.B.
Sun	Total	,, June 29	6 a.m.	Total across England, Norway, etc. *See* maps, pp. 229, 763.
Moon	Total	,, Dec. 8	6 p.m.	All except beginning visible G.B.
Sun	Partial	1928, Nov. 12	9 a.m.	$\frac{1}{5}$ eclipsed in G.B.
Moon	Total	,, Nov. 27	9 a.m.	Beginning of eclipse visible G.B. just before sunrise.
Sun	Total	1929, May 9	6 a.m.	Total Sumatra, etc., invisible G.B.
Sun	Annular	,, Nov. 1	Noon	$\frac{1}{5}$ eclipsed in G.B. Annular Sierra Leone, etc.
Sun	Ann. Tot.	1930, April 28	7 p.m.	Very short totality N. America. Invisible G.B.
Moon	Partial	,, Oct. 7	7 p.m.	Very small eclipse on N. edge of Moon. Visible G.B.
Moon	Total	1931, April 2	8 p.m.	Visible G.B. Begins about sunset.
Moon	Total	,, Sept. 26	8 p.m.	Visible G.B. Begins about sunset.
Sun	Total	1932, Aug. 31	8 p.m.	Total Eastern Canada. Invisible G.B.
Moon	Partial	,, Sept. 14	9 p.m.	Almost total. Visible G.B.
Moon	Partial	1934, Jan. 30	5 p.m.	Very small eclipse. Moon rises eclipsed G.B.
Sun	Total	,, Feb. 14	1 a.m.	Total Borneo, etc. Invisible G.B.
Moon	Total	1935, Jan. 19	4 p.m.	Middle and end visible G.B.
Moon	Total	,, July 16	5 a.m.	Only beginning visible G.B.
				Seven eclipses—5 Sun, 2 Moon—in 1935. Greatest number possible.
Moon	Total	1936, Jan. 8	6 p.m.	Visible G.B. Begins soon after sunset.
Sun	Total	,, June 19	5 a.m.	$\frac{1}{2}$ Sun eclipsed in G.B. Total Constantinople, etc.
Sun	Total	1937, June 8	9 p.m.	Invisible G.B. Total Pacific and S. America.
Moon	Total	1938, Nov. 7	10 p.m.	The next really favourable total lunar eclipse in G.B. All the preceding ones are rather low down.
Sun	Annular	1939, April 19	5 p.m.	$\frac{1}{5}$ eclipsed in G.B. Annular near North Pole.
Moon	Total	,, Oct. 28	7 a.m.	Beginning and middle visible G.B.
Sun	Total	1940, Oct. 1	1 p.m.	Total Brazil, S. Africa. Invisible G.B.
Sun	Total	1941, Sept. 21	5 a.m.	Total Caspian, China, etc. Invisible G.B.
Moon	Total	1942, March 2	11 p.m.	Favourably visible in G.B.
Moon	Total	,, Aug. 26	4 a.m.	Visible in G.B. except end.
Sun	Partial	,, Sept. 10	4 p.m.	$\frac{1}{3}$ eclipsed in G.B.
Sun	Total	1943, Feb. 4	11 p.m.	Invisible G.B. Total Japan, etc.
Moon	Partial	,, Feb. 20	6 a.m.	$\frac{7}{10}$ eclipsed. Visible in G.B. Low down at end.
Moon	Partial	,, Aug. 15	7 p.m.	$\frac{8}{10}$ eclipsed. Middle and end visible G.B.
Sun	Total	1944, Jan. 25	3 p.m.	Invisible G.B. Total Brazil, Gold Coast, etc.
Sun	Total	1945, July 9	1 p.m.	$\frac{3}{5}$ eclipsed G.B. Total Norway, etc.; map, p. 229.
Moon	Total	,, Dec. 19	2 a.m.	Favourably visible in G.B.
Moon	Total	1946, June 14	7 p.m.	End visible in G.B.
Moon	Total	,, Dec. 8	6 p.m.	Visible in G.B. Low down at beginning.
Sun	Total	1947, May 20	2 p.m.	Invisible G.B. Total Brazil, Central Africa.
Sun	Total	1948, Nov. 1	6 a.m.	Invisible G.B. Total Zanzibar, Madagascar, etc.
Moon	Total	1949, April 13	4 a.m.	Visible in G.B. except end.
Sun	Partial	,, April 28	8 a.m.	$\frac{1}{5}$ eclipsed in G.B.
Moon	Total	,, Oct. 7	3 a.m.	Favourably visible in G.B.

THE IMPORTANT ECLIPSES OF THE NEXT 50 YEARS, 1925 TO 1974—*continued.*

Body Eclipsed.	Total or Partial.	Date	Approximate Greenwich Time.	Description.
Moon	Total	1950, April 2	9 p.m.	Visible in G.B. Low down at beginning.
Moon	Total	,, Sept. 26	4 a.m.	Visible in G.B. Low down at end.
Sun	Annular	1951, Sept. 1	1 p.m.	Small partial eclipse in G.B. Annular N.W. Africa, etc.
Moon	Partial	1952, Feb. 11	1 a.m.	$\frac{1}{10}$ of Moon eclipsed. Favourably visible G.B.
Sun	Total	,, Feb. 25	9 a.m.	$\frac{1}{10}$ eclipsed in G.B. Total Central Africa, Upper Egypt.
Moon	Partial	,, Aug. 5	8 p.m.	$\frac{1}{2}$ of Moon eclipsed. End visible in G.B.
Moon	Total	1953, Jan. 29	11 p.m.	Favourably visible in G.B.
Moon	Total	1954, Jan. 19	2 a.m.	Favourably visible in G.B.
Sun	Total	,, June 30	Noon	Total Labrador, Norway, Russia. Large eclipse in G.B. May be just total in Unst, Shetlands.
Moon	Partial	,, July 16	1 a.m.	$\frac{2}{5}$ of Moon eclipsed. Visible G.B.
Sun	Total	1955, June 20	4 a.m.	Invisible G.B. Total Ceylon, Siam, etc. This is a record totality for length. Over 7 minutes in Philippines.

DELPHINUS. SAGITTA & VULPECULA·ET·ANSER. No. 23.

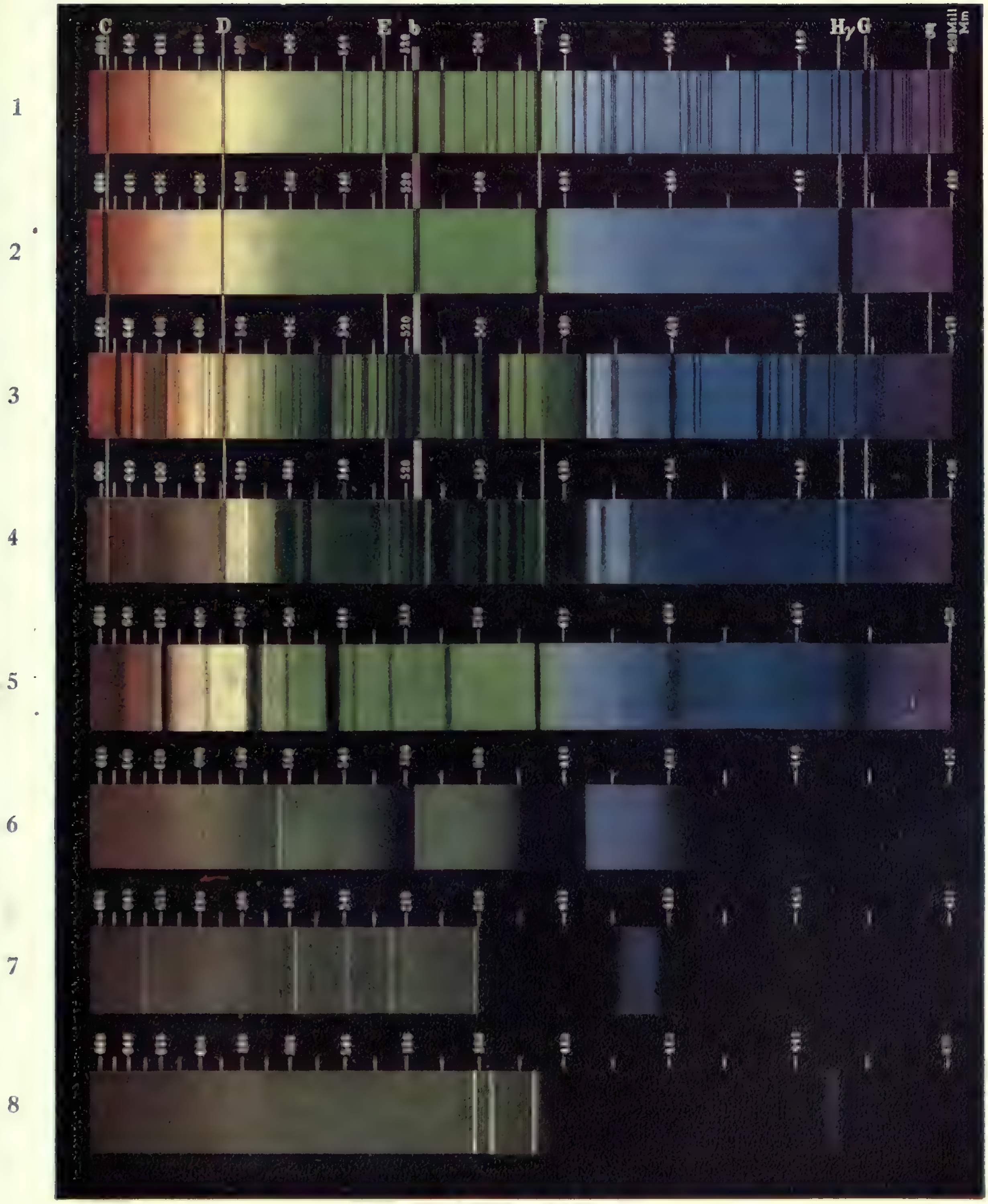


The Important Eclipses of the Next 50 Years, 1925 to 1974—*continued.*

Body Eclipsed.	Total or Partial.	Date	Approximate Greenwich Time.	Description.
Moon	Partial	1955, Nov. 29	5 p.m.	$\frac{1}{5}$ of Moon eclipsed. Visible G.B., low down.
Moon	Total	1956, Nov. 18	7 a.m.	Beginning and middle, visible G.B.
Moon	Total	1957, May 13	11 p.m.	Favourably visible in G.B.
Moon	Partial	1959, Mar. 24	8 p.m.	$\frac{1}{4}$ of Moon eclipsed, visible G.B.
Sun	Total	,, Oct. 2	1 p.m.	$\frac{1}{3}$ eclipsed G.B. Total Northern Africa.
Sun	Total	1961, Feb. 15	8 a.m.	$\frac{9}{10}$ eclipsed G.B. soon after sunrise. Total S. France, Italy, etc.
Moon	Total	,, Aug. 26	3 a.m.	Visible G.B.
Sun	Total	1962, Feb. 5	1 a.m.	Invisible G.B. Total New Guinea, etc.
Moon	Partial	1963, July 6	10 p.m.	$\frac{2}{3}$ of Moon eclipsed. Visible G.B.
Sun	Total	,, July 20	9 p.m.	Invisible G.B. Total Canada, etc. *See* map. p. 229.
Moon	Total	1964, June 25	1 a.m.	Visible G.B.
Moon	Total	,, Dec. 19	3 a.m.	Favourably visible G.B.
Moon	Partial	1965, June 14	2 a.m.	$\frac{1}{6}$ of Moon eclipsed. Visible G.B.
Sun	Ann. Tot.	1966, May 20	10 a.m.	$\frac{1}{2}$ eclipsed G.B. Total for few seconds in Greece, etc.
Moon	Total	1968, April 13	5 a.m.	Beginning visible in G.B., low down.
Sun	Total	,, Sept. 22	11 a.m.	$\frac{1}{3}$ eclipsed G.B. Total Nova Zembla, etc.
Sun	Total	1970, Mar. 7	6 p.m.	Invisible G.B. except West of Ireland. Total Mexico, Florida, etc.
Moon	Partial	,, Aug. 17	3 a.m.	$\frac{2}{5}$ of Moon eclipsed. Visible G.B.
Moon	Total	1971, Feb. 10	8 a.m.	Beginning visible G.B., low down.
Sun	Partial	,, Feb. 25	10 a.m.	$\frac{1}{2}$ eclipsed G.B.
Moon	Total	,, Aug. 6	8 p.m.	Middle and end visible G.B., low down.
Sun	Total	1972, July 10	8 p.m.	$\frac{1}{2}$ eclipsed G.B. at sunset. Total Hudson's Bay, S.E. Canada.
Sun	Total	1973, June 30	Noon	Total N. Africa for 7 minutes. Partial in France but not in G.B.
Moon	Partial	,, Dec. 10	2 a.m.	$\frac{1}{10}$ of Moon eclipsed. Visible G.B.
Sun	Annular	,, Dec. 24	3 p.m.	$\frac{1}{3}$ eclipsed G.B. just before sunset. Annular Brazil, etc.
Moon	Partial	1974, June 4	10 p.m.	$\frac{4}{5}$ of Moon eclipsed. Visible G.B.
Moon	Total	,, Nov. 29	3 p.m.	End visible G.B., low down.

FURTHER TOTAL ECLIPSES OF SUN IN BRITISH ISLES.

1999, August 11, 11 a.m., total Cornwall, very favourable (map, p. 229) ; 2090, September 23, south coast of Ireland and England, low Sun ; 2135, October 7 (low Sun) ; 2142, May 25, total at Dover ; 2,151, June 14, total right across England ; 2,160, June 4, total in S.W. of Ireland ; 2,189, November 8, total soon after sunrise ; 2200, April 14, total from Belfast to Hartlepool. From this point I simply give the year : 2381, 2426, 2442, 2545, 2600, 2681, 2817, 2864, 2911 (Shetlands), 2927, 2972. This gives on the average about one eclipse of Sun in 62 years total in British Isles. About 38 partial eclipses of Sun are visible there in a century.



SOME TYPICAL SPECTRA.

(Parts of Spectra observed visually)

1. Spectrum of the Sun. Dark lines mainly due to absorption by metallic vapours in the Sun's atmosphere.

2. Spectrum of Sirius. Hydrogen lines at C, F and Hγ strong and broad. A few metallic lines shown.

3. Spectrum of α Orionis (Betelgeuse). The broad bands or flutings sharp towards the violet are due to titanium oxide absorption.

4. Spectrum of Nova Cygni, 1876 Dec. 8. Bright lines due to hydrogen and other elements.

5. Spectrum of Uranus. The narrow lines due to reflected sunlight; the broad bands to absorption by gases in the planet's atmosphere.

6. Spectrum of a Comet. Bright bands due to carbon monoxide.

7. Spectrum of the Aurora. Most of the bright lines are due to nitrogen. The most prominent green line is of unknown origin.

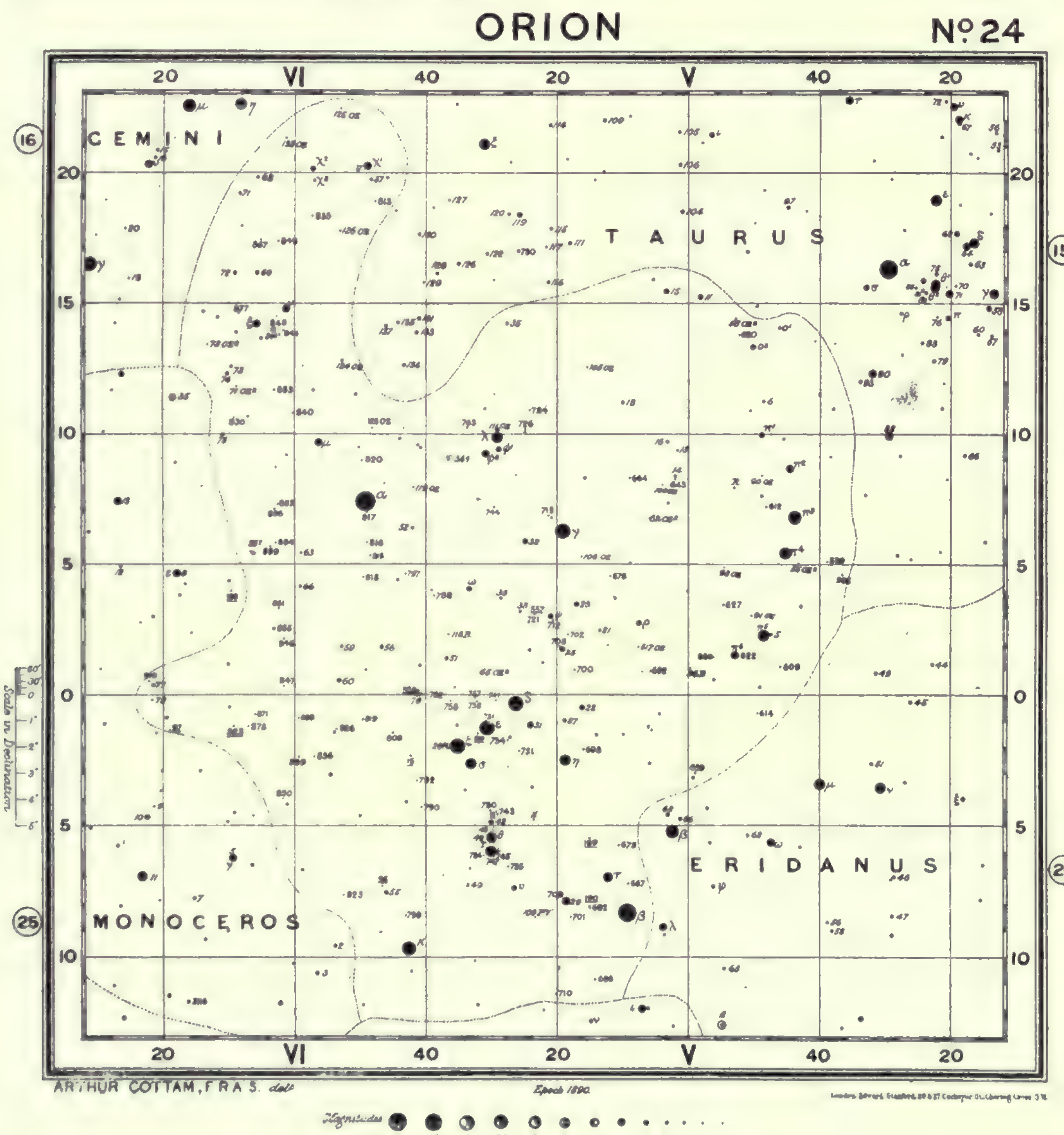
8. Spectrum of the Orion Nebula. Bright lines of hydrogen at wave length 4861 and Nebulium at wave length 4959 and 5007.

N.B.—In comparing the above with photographic spectra it must be remembered that in the latter according to the modern convention, the red end of the spectrum is on the right.

PROPER NAMES OF STARS.

(See also Chapter XVII).

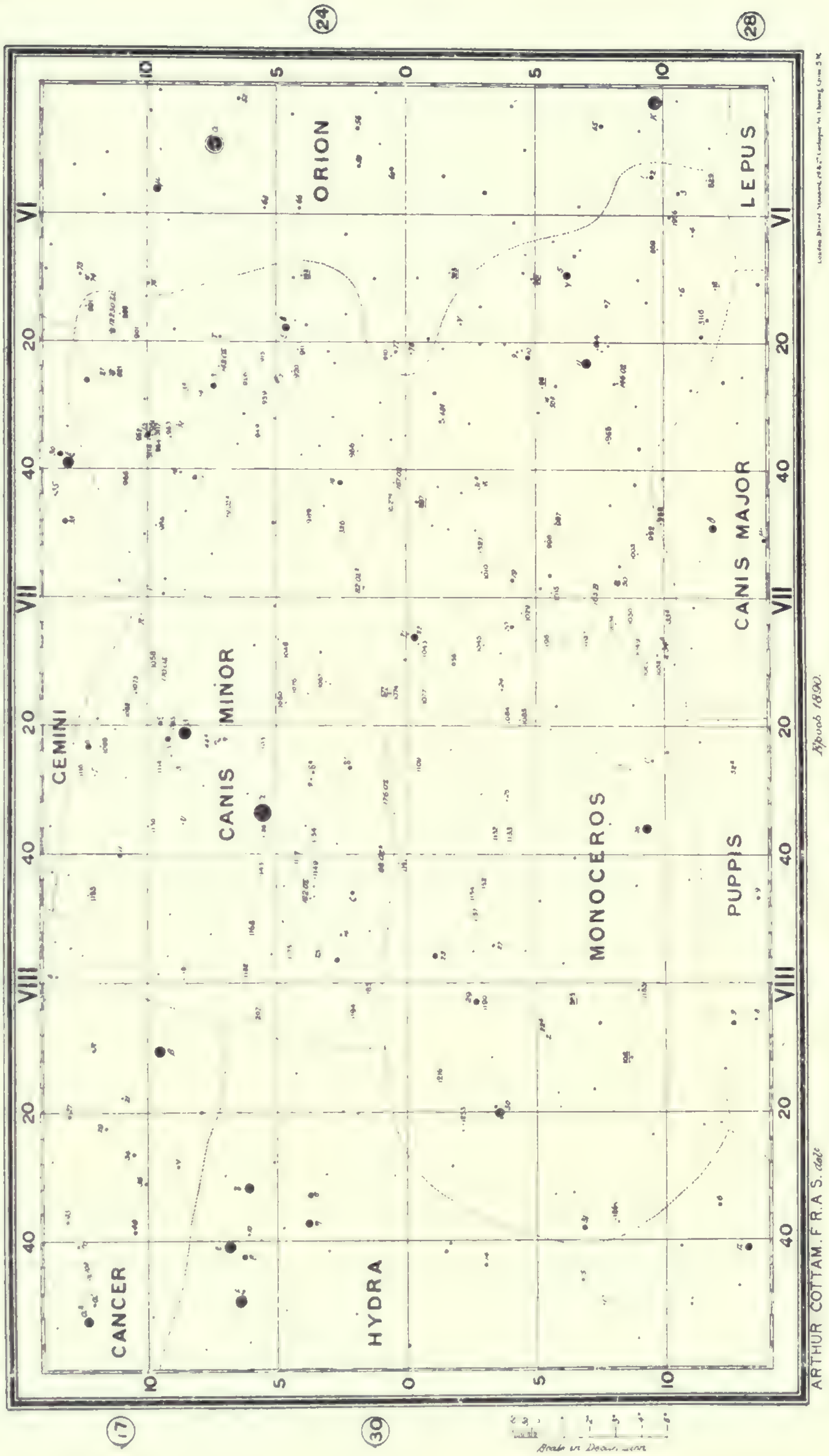
α	Andromedae	*Alpheratz, Sirrah*
β	,,	*Mirac, Mirach, Mizar*
γ	,,	*Almak, Almach*
α	Aquarii	*Sadalmelik, Sadlamulk*
β	,,	*Sadalsud, Sadalsund*
γ	,,	*Sadachbia*
δ	,,	*Skat, Sheat, Scheat*
α	Aquilae	*Altair, Atair*
β	,,	*Alshain, Alshairn*
γ	,,	*Tarazed*
α	Argûs	*Canopus*
α	Arietis	*Hamal*
β	,,	*Sheratan, Sharatain*
γ	Arietis	*Mesarthim, Mesartim*
α	Aurigae	*Capella*
β	,,	*Menkalinan*
α	Boötis	*Arcturus*
β	,,	*Nekkar*
ε	,,	*Izar, Mirac, Mirach, Mizar, Pulcherrima*
η	,,	*Muphrid*
μ	,,	*Alkalurops*
α	Canum Venaticorum	*Cor Caroli*
α	Canis Majoris	*Sirius*
β	,, ,,	*Mirzam*
ε	,, ,,	*Adara*



Proper Names of Stars—*continued*.

α Canis Minoris	*Procyon*
β ,, ,,	*Gomeisa*
α Capricorni	*Giedi*
δ ,,	*Deneb Algiedi*
α Cassiopeiae	*Schedir, Shedir, Schedar*
β ,,	*Caph, Chaph*
α Cephei	*Alderamin*
β ,,	*Alphirk*
γ ,,	*Alrai, Errai*
α Ceti	*Mekab, Menkab, Menkar*
β ,,	*Diphda*
ζ ,,	*Baten Kaitos*
ι ,,	*Deneb Kaitos Shemali*
ο ,,	*Mira*
α Columbae	*Phakt, Phact*
α Coronae Borealis	*Alphecca, Alphekka*
α Corvi	*Alchiba, Alkhiba, Gemma*
δ ,,	*Algoral, Algorel, Algores*
α Crateris	*Alkes*
α Cygni	*Arided, Deneb el Adige*
β ,,	*Albireo*
π ,,	*Azelfafage*
α Delphini	*Svalocin* (= *Nicolaus*)
β ,,	*Rotanev* (= *Venator*)
α Draconis	*Thuban*
β ,,	*Alwaid*
γ ,,	*Etamin, Etanin, Rastaban, Rasaben*
α Eridani	*Achernar*
β ,,	*Cursa, Kursa*
γ ,,	*Zaurak*
40 ,,	*Keid*
α Geminorum	*Castor*
β ,,	*Pollux*
γ ,,	*Alhena*
δ ,,	*Wasat*
ε ,,	*Mebsuta*
α Herculis	*Ras Algethi, Rasalegti*
β ,,	*Kornephoros*
κ ,,	*Marsik*
α Hydrae	*Alphard, Cor Hydrae*
α Leonis	*Regulus, Cor Leonis*
β ,,	*Deneb Aleet, Denebola*
γ ,,	*Algeiba, Algieba*
δ ,,	*Zosca, Zosma*
α Leporis	*Arneb*
α Librae	*Zuben el Genubi*
β ,,	*Zuben el Chamali, Zubenesch, Zubenelg*

γ Librae	*Zuben el Hakrabi*
α Lyrae	*Vega, Wega*
β ,,	*Sheliak*
γ ,,	*Sulaphat*
α Ophiuchi	*Ras Alhagua, Ras-al-hague*
β ,,	*Kelb-al-Rai, Celb-al-Rai*
δ ,,	*Yed*
α Orionis	*Betelgeux, Belelgeuze*
β ,,	*Rigel*
γ ,,	*Bellatrix*
δ ,,	*Mintaka*
ε ,,	*Alnilam*
α Pegasi	*Markab*
β ,,	*Scheat, Sheat*
γ ,,	*Algenib*
ε ,,	*Enif, Fom*
ζ ,,	*Homam, Homan*
α Persei	*Mirfak, Mirphak*
β ,,	*Algol*
α Piscis Australis	*Fomalhaut*
α Piscium	*Kaïtain, Okda*
ε Sagittarii	*Kaus Australis*
α Scorpii	*Antares, Cor Scorpii*
β ,,	*Acrab, Akrab*
α Serpentis	*Unukalhay, Cor Serpentis*
α Tauri	*Aldebaran*
β ,,	*Nath*
η ,,	*Alcyone*
17 ,,	*Electra*
19 ,,	*Taygete*
20 ,,	*Maia*
21 ,,	*Asterope*
23 ,,	*Merope*
27 ,,	*Atlas*
28 ,,	*Pleione*
α Ursae Majoris	*Dubhe*
β ,, ,,	*Merak*
γ ,, ,,	*Phecda, Phekha*
δ ,, ,,	*Megrez*
ε ,, ,,	*Alioth*
ζ ,, ,,	*Mizar*
η ,, ,,	*Alkaid, Benetnasch*
ι ,, ,,	*Talitha, Talita*
80 ,, ,,	*Alcor*
α Ursae Minoris	*Polaris, Alruccabah*
β ,, ,,	*Kocab, Kochab*
α Virginis	*Spica, Azimech*
β ,,	*Zawijah, Zavijava*
ε ,,	*Vindemiatrix, Protrygetor*



No. 25. CANIS MINOR & MONOCEROS.

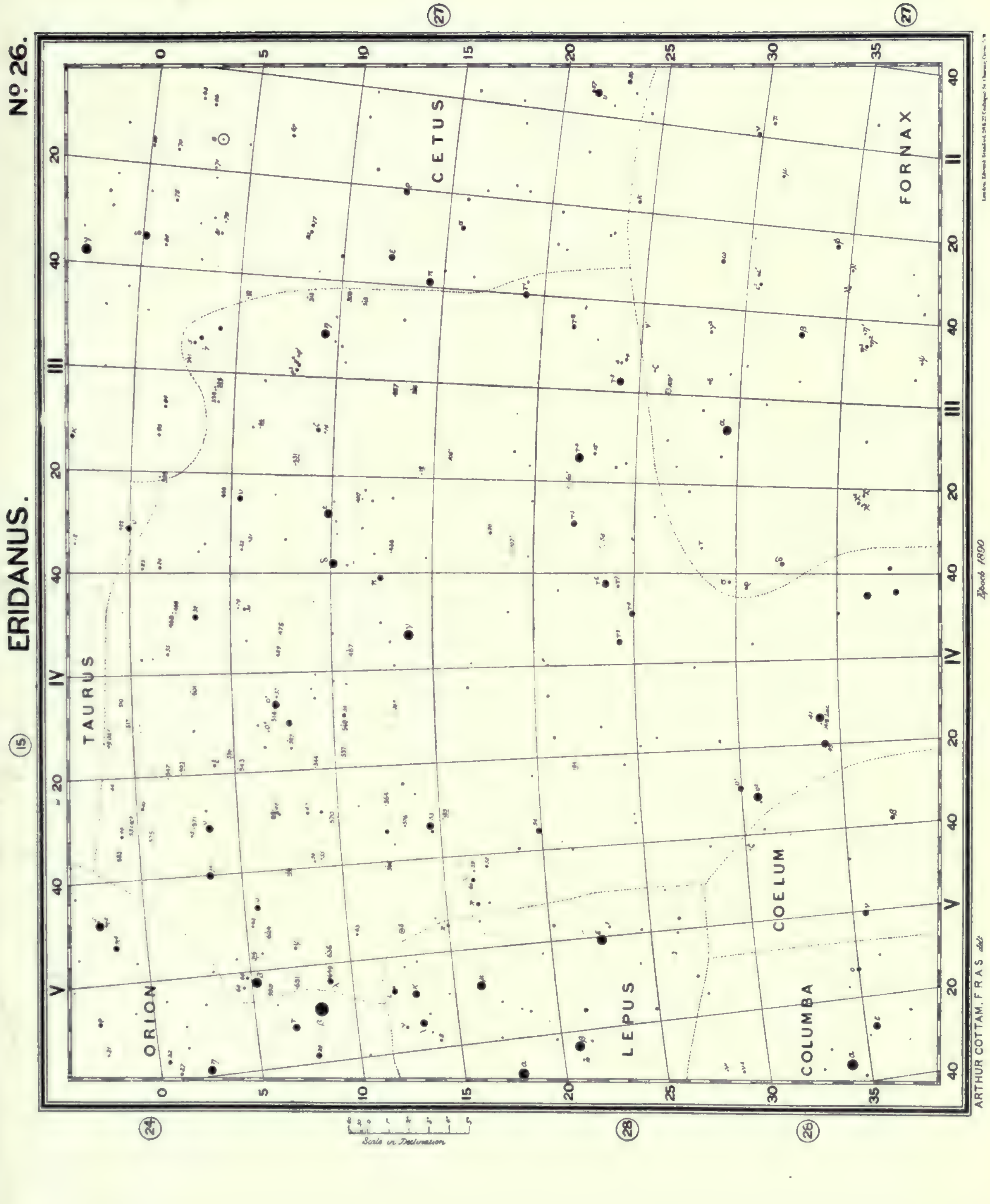
PRONUNCIATIONS AND MEANINGS OF NAMES OF STARS AND CONSTELLATIONS.

1. Stars.

Name.	Pronunciation.	Meaning.
Achernar	ak′-er-nar	End-of-the-River
Aldebaran	al-deb-ar-ân	The Hindmost
Altair	al-tair′	—
Antares	an′-ta-rez	Rival of Ares (Mars)
Arcturus	ärk-tu′-rus	—
Bellatrix	bel′-la-trix	The Female Warrior
Betelgeuze	bet′-el-jooz	The Arm-Pit
Canopus	can-o′-pus	—
Capella	ca-pel′-la	Little She-Goat
Deneb	den′-eb	—
Denebola	de-neb′-o-la	The Lion's Tail
Fomalhaut	fom′-al-howt	The Fish's Mouth
Hyades	hi′-a-dez	The Rainy Ones
Pleiades	ply′-ad-ez	—
Pollux	pol′-lux	—
Praesepe	pre-se′-pe	The Bee-hive
Procyon	pro′-se-on	Precursor of the Dog
Regulus	reg′-u-lus	The Ruler
Rigel	ri′-gel or ri-jel	—
Sirius	sy′-re-us	The Sparkling One
Spica	spi′-ka	The Ear of Wheat
Vega	ve′-ga	—

2. Constellations.

Name.	Pronunciation.	Meaning.
Andromeda	an-drom′-e-da	The Chained Woman
Antinous	ant-in′-o-us	—
Aquarius	a-kwa′-ri-us	The Water-bearer
Aquila	ak′-wi-la	The Eagle
Ara	a′-ra	The Altar
Argo Navis	är′-go-nav′-is	The Ship Argo
Aries	ar′ry-eez	The Ram
Auriga	äw-ri′-ga	The Charioteer
Boötes	bo-o′-tez	The Herdsman
Cancer	can′-ser	The Crab
Canes Venatici	can′-es ven-at′-i-si	The Hunting Dogs
Canis Major	can′-is ma′jor	The Greater Dog
Canis Minor	can′-is mi′nor	The Lesser Dog
Capricornus	cap′-ri-kor′-nus	The Goat
Cassiopeia	cas′-si-o-pe′-ya	—
Centaurus	cen-taw′-rus	The Centaur
Cepheus	se′-fe-us	—
Cetus	se′-tus	The Whale
Columba	col-um′-ba	The Dove
Coma Berenices	co′ma ber-e-ni′-ses	Berenice's Hair
Corona Borealis	co-ro′-na bo-re-a′-lis	The Northern Crown
Corvus	cor′-vus	The Crow
Crater	cra′-ter	The Cup
Crux	krux	The Cross
Cygnus	sig′-nus	The Swan
Delphinus	del-fi′-nus	The Dolphin
Dorado	dòr-a′-do	The Gold-fish
Draco	dra′-co	The Dragon
Eridanus	e-rid′-a-nus	The River Eridanus
Gemini	jem′-i-ni	The Twins


No. 26.
ERIDANUS.
CETUS
FORNAX
TAURUS
ORION
LEPUS
COELUM
COLUMBA
Epoch 1890
Magnitudes
ARTHUR COTTAM, F.R.A.S. delt
Scale in Declination

CONSTELLATIONS—*continued.*

Name.	Pronunciation.	Meaning.
Grus ...	grus ...	The Crane
Hercules	her'-ku-lez	—
Hydra	hi'dra	The Water-snake
Hydrus	hi'-drus	The Serpent
Indus ...	ind'-us	The Indian
Leo ...	le'-o ...	The Lion
Lepus	lep'-us	The Hare
Libra ...	li'-bra ...	The Scales
Lupus	lu'-pus	The Wolf
Lynx	—	The Lynx
Lyra ...	li'-ra	The Lyre
Musca...	mus'-ca	The Fly
Monoceros	mon-os'-er-os ...	The Unicorn
Octans	oct'-ans	The Octant
Ophiuchus	off'-i-u'-kus	The Serpent-holder
Orion ...	o-ri'-on	The Warrior
Pavo ...	pā'-vo ...	The Peacock
Phœnix	fe'-nix ...	—
Piscis Australis	pis'-sis aus-tra'-lis	The Southern Fish
Pegasus	pe'ga-sus	The Winged Horse
Perseus	per'-suse or per'-se-us	—
Pisces	pis'-sez	The Fishes
Sagitta	sa-jit'-ta	The Arrow
Sagittarius	sa-jit-ta'-ri-us...	The Archer
Scorpio	skôr'-pi-o	The Scorpion
Scutum Sobieskii	scu'-tum sob-i-esk'-i-i	—
Serpens	ser'-pens	The Serpent
Taurus	tau'-rus	The Bull
Telescopium ...	tel-es-cop'-i-um	The Telescope
Triangulum ...	tri-an'-gu-lum	The Triangle
Toucanus	tu'-can-us	The Toucan
Ursa Major ...	ur'-sa ma'-jor	The Greater Bear
Ursa Minor ...	ur'-sa mi'-nor	The Lesser Bear
Virgo	ver'-go	The Maiden
Volans	vol'-ans	The Flying Fish
Vulpecula et Anser ...	vul-pec'-u-la ...	The Fox and Goose

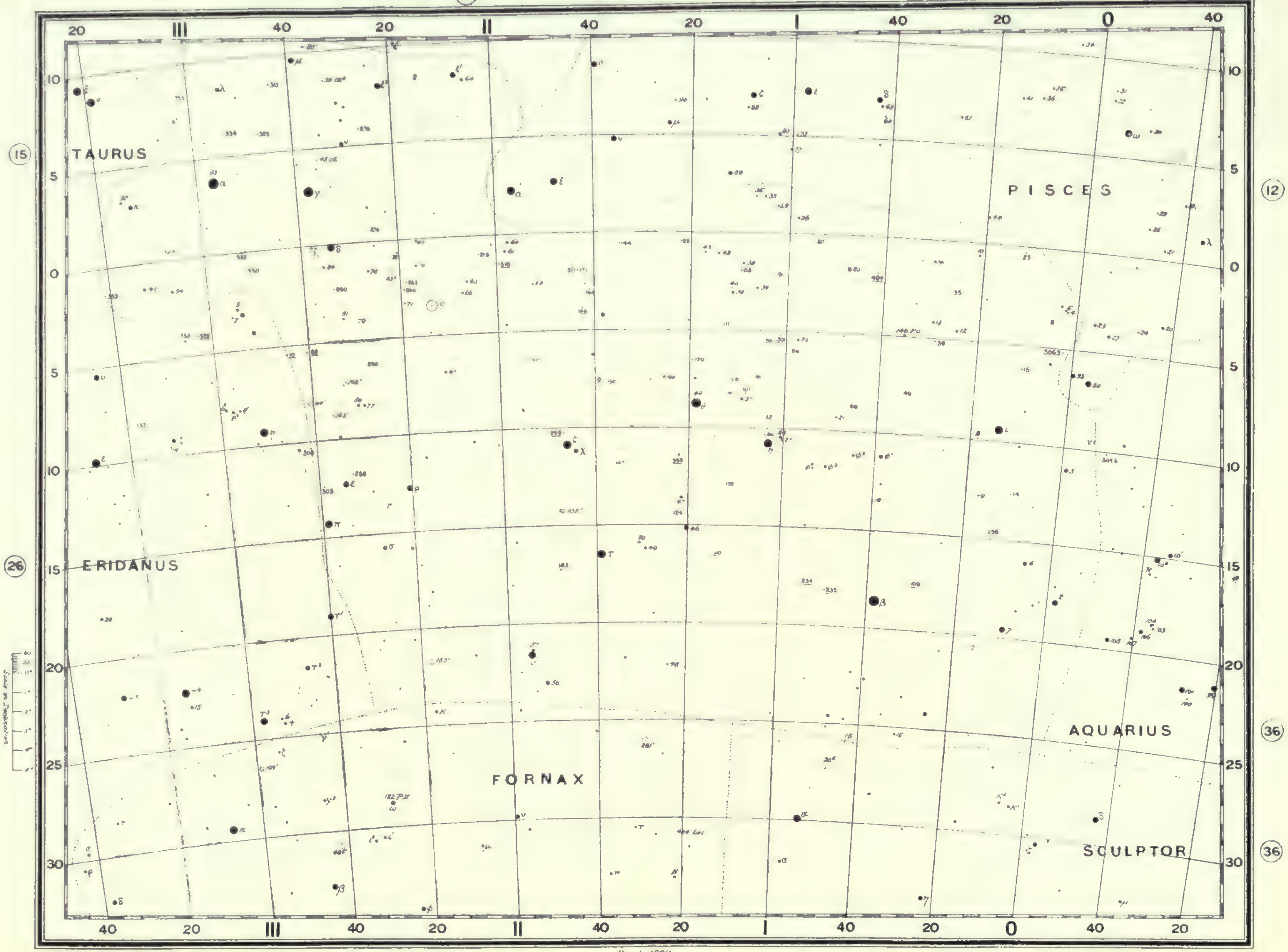
STELLAR MAGNITUDES AND SPECTRA.

In this table are given examples, where possible, of stars representing every tenth of a magnitude down to 6·0*m*. The magnitudes are visual (*see* Chapter XV), as determined photometrically at Harvard, and are given to the nearest 0·1*m*. In addition, the spectral type of each star is recorded, and a comparison of the list with the tints of the several stars as seen in a telescope (preferably a reflector) will demonstrate to the observer the close relation existing between colour and spectral type (*see* Chapter XII). Generally speaking, the M stars appear of an orange-red to pure orange colour; the K stars orange to deep yellow; the G stars yellow to yellowish white; the F stars yellowish white to nearly pure white; the A stars pure white; and the B stars a somewhat bluish white.

Mag.	Star.	Spectral Type.	Mag.	Star.	Spectral Type.
—1·6	Sirius ...	Ao	0·9	Altair ...	A5
—0·9	Canopus ...	Fo	1·1	Aldebaran	K5
0·1	Vega ...	Ao	1·2	Spica ...	B2
0·2	Capella ...	Go	1·3	Fomalhaut	A3
0·3	Rigel ...	B8	1·5	β Crucis ...	B1
0·5	Procyon ...	F5	1·6	Castor ...	Ao
0·6	Achernar ...	B5	1·7	γ Orionis ...	B2

CETUS.

No. 27.



ARTHUR COTTAM, F.R.A.S. delt

Epoch 1890

Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 Telescopic

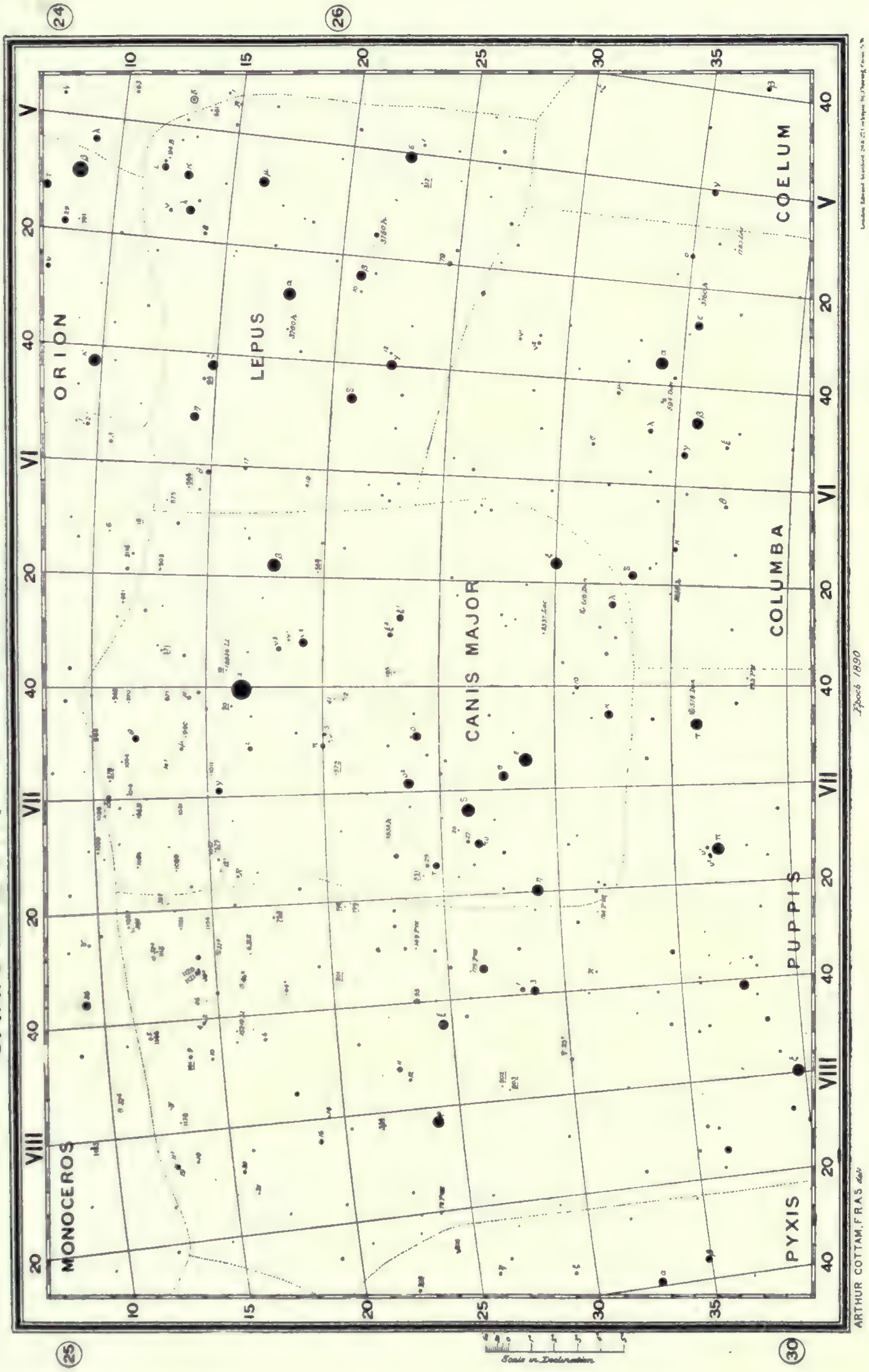
Stellar Magnitudes and Spectra—*continued.*

Mag.	Star.	Spectral Type.
1·8	β Tauri	B8
1·9	α Persei	F5
2·0	β Canis Majoris	B1
2·1	Polaris	F8
2·2	α Andromedae	Ao
2·3	γ Cassiopeiae	Bo
2·4	β Cassiopeiae	F5
2·5	δ Orionis	Bo
2·6	δ Leonis	A2
2·7	β Arietis	A5
2·8	δ Cassiopeiae	A5
2·9	ζ Persei	B1
3·0	ε Persei	B1
3·1	γ Persei	F5
3·2	μ Geminorum	Ma
3·3	θ Ursae Majoris	F8
3·4	δ Ursae Majoris	A2
3·5	δ Geminorum	Fo
3·6	β Boötis	G5
3·7	η Piscium	G5
3·8	β Virginis	F8
3·9	μ Andromedae	A2
4·0	δ Ceti	B2
4·1	μ Leonis	Ko
4·2	μ Eridani	B5
4·3	τ Virginis	A2
4·4	θ Virginis	Ao
4·5	υ Leonis	Ko
4·6	π Virginis	A3
4·7	χ Leonis	Fo
4·8	μ Aquarii	A3
4·9	π Leonis	Ma
5·0	ρ Virginis	Ao
5·1	ω Aquilae...	A5
5·2	φ Pegasi	Ma
5·3	κ Aquarii	Ao
5·4	κ Fornacis...	F5
5·5	η Cancri	Ko
5·6	ζ Piscium	A5
5·7	θ Arietis	Ao
5·8	96 Aquarii	Fo
5·9	32 Librae	Ko
6·0	44 Piscium	G5

THE NEAREST STARS.

Star.	R.A. 1925·0.	Dec. 1925·0.	Parallax.	Distance. Light Years.	Distance. Parsecs.	Magnitude. Vis.	Magnitude. Abs.	Luminosity Sun=1	Annual P.M.	Spectrum.
	h. m.	° ′	″						″	
Proxima Centauri ...	14 24·6	−62 22	0·79	4·1	1·2	11·0	15·5	0·0001	3·85	—
α¹ Centauri	14 34·5	−60 32	0·76	4·3	1·3	0·3	4·7	1·3	3·68	Go
Munich 15040 ...	17 54·2	+ 4 29	0·53	6·2	1·9	9·4	13·0	0·0005	10·29	Mb
Lalande 21185 ...	10 59·2	+36 28	0·41	7·9	2·4	7·6	10·7	0·0054	4·78	Mb
Sirius	6 41·8	−16 37	0·38	8·6	2·6	−1·6	1·3	30	1·32	Ao
Anonymous	11 13·1	−57 10	0·34	9·6	2·9	12	15	0·0001	2·69	—
Cordoba V[h] 243 ...	5 8·7	−44 59	0·32	10·2	3·1	9·2	11·7	0·0022	8·75	K2
τ Ceti	1 40·6	−16 20	0·32	10·2	3·1	3·6	6·1	0·35	1·92	Ko
ε Eridani	3 29·4	− 9 43	0·31	10·5	3·2	3·8	6·3	0·31	0·97	Ko
Procyon	7 35·4	+ 5 25	0·30	10·9	3·3	0·5	2·9	7·0	1·24	F5
61¹ Cygni	21 3·5	+38 23	0·30	10·9	3·3	5·6	8·0	0·064	5·27	K5
Lacaille 9352 ...	23 1·0	−36 17	0·29	11·2	3·5	7·4	9·7	0·013	6·90	Ma
Pos. Med. 2164 ...	18 41·9	+59 31	0·29	11·2	3·5	8·8	11·1	0·0036	2·31	Mb
ε Indi	21 57·6	−57 6	0·28	11·6	3·6	4·7	6·9	0·17	4·69	K5
Groombridge 34 ...	0 14·1	+43 36	0·28	11·6	3·6	8·1	10·3	0·0073	2·89	Ma
Krüger 60	22 25·3	+57 19	0·26	12·5	3·8	9·3	11·4	0·0028	0·87	K5
O.A. (N.) 17415–6 ...	17 36·9	+68 24	0·25	13·0	4·0	9·5	11·5	0·0025	1·33	K
Anonymous	0 44·9	+ 5 2	0·24	13·6	4·2	12·3	14·2	0·0002	3·01	Fo
Altair	19 47·1	+ 8 40	0·22	14·8	4·5	0·9	2·6	9·0	0·66	A5
Gould 32416 ...	0 1·0	−37 44	0·22	14·8	4·5	8·5	10·2	0·0082	6·11	—
Lalande 25372 ...	13 41·9	+15 18	0·21	15·5	4·8	8·5	10·1	0·0009	2·30	K2
o² (40) Eridani ...	4 11·9	− 7 44	0·20	16·3	5·0	4·5	6·0	0·40	4·09	G5
W.B. XVI[h] 1259 ...	16 42·3	+33 38	0·20	16·3	5·0	8·6	10·1	0·0090	0·37	K8
O.A. (N.) 11677 ...	11 16·2	+66 15	0·20	16·3	5·0	9·2	10·7	0·0052	2·99	Ma
W.B. X[h] 234 ...	10 15·6	+20 15	0·20	16·3	5·0	9·2	10·7	0·0052	0·49	Md

CANIS MAJOR, PUPPIS, LEPUS & COLUMBA. Nº 28.



ANGULAR MEASURE.

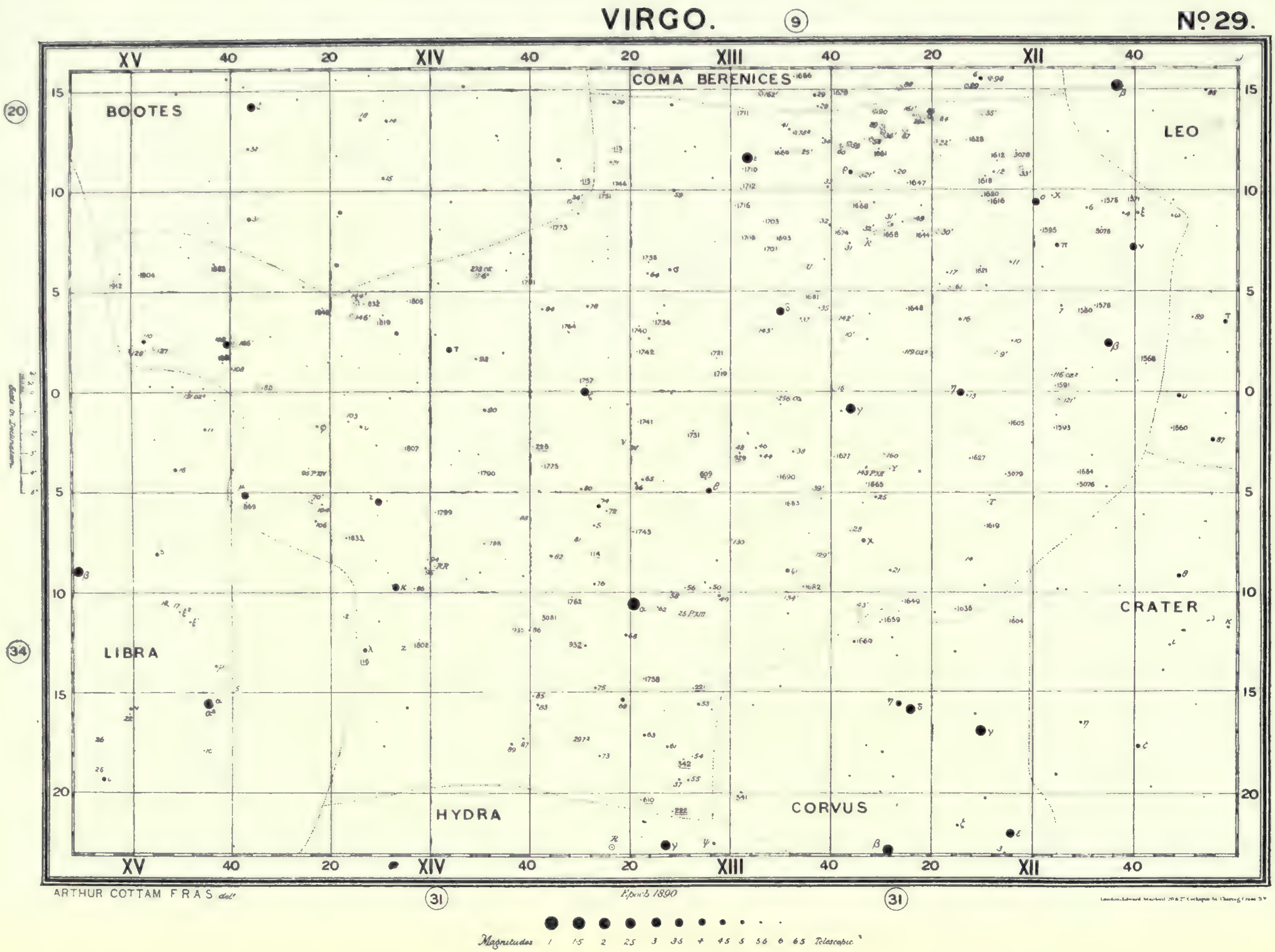
When, as in astronomical observations, we are dealing with objects that are inaccessible and situated at various distances from us, we are primarily concerned with their *apparent* (or angular) rather than with their *actual* (or linear) dimensions. Of course, the latter are readily deducible from the former when the distances of the objects are known; but, for the purpose of describing the *appearance* as presented to the observer, we must obviously employ some system that is independent of any exact knowledge of the realities concerned. Hence the system of angular measure, which is so independent, is universally adopted for descriptive purposes in Astronomy and allied Sciences. The principle of angular subtense is illustrated by the simple diagram on page 462. Such a diagram, however, will not alone suffice to convey to the reader what an angle of one degree actually "looks like," since the two stars there shown are only seen separated by that amount from the point of view of an imaginary observer placed at the point of intersection of the two lines, or from other points at exactly the same distance from the two stars, and lying in a plane at right angles to the line bisecting them. A much better idea of the appearance of various angles (which are reckoned as arcs of a "great circle") as projected on the sky can be obtained by observing and memorising the apparent distances between certain well-known stars. After a little practice, the observer will find that he can estimate angles with considerable precision, and the experience thus gained will prove valuable if at any time he requires to describe to others his impressions of, say, the length of a meteor trail or comet's tail, or the apparent width of the base of the Zodiacal Light. Not infrequently such statements as "The meteor looked about six feet long" or ". . . passed about two inches below the Moon," occur in reports published in the Press or sent to astronomers. Descriptions like these may mean something to those who write them, but they are quite unintelligible to anyone else, and utterly unscientific. If an observer *must* speak in terms of linear measure, through inexperience of the angular system, he should always indicate at what *distance from the eye* the scale used is imagined to be. Thus the expression "as long as a foot-rule at arm's length" may quite legitimately be used, though it is better to learn the more orthodox method.

Below are given examples of angles of various size, which will serve as standards for the estimation of apparent distances in the sky:

360°	All round the horizon.
180°	East to West, along horizon or through Zenith.
90°	Horizon to Zenith.
60° (about)	α Ursae Majoris to β Cassiopeiae.
30° ,, ...	Polaris to β Cassiopeiae.
20° ,, ...	α to β Orionis.
15° ,, ...	α to β Andromedae.
10° ,, ...	α to δ Orionis, β to δ Leonis.
5° ,, ...	α to β Ursae Majoris, α to β Cassiopeiae.
4° ,, ...	α to β Geminorum, α to β Canis Minoris.
3° ,, ...	β to δ Scorpii.
2½° ,, ...	α to β Aquilae.
2° ,, ...	β to γ Lyrae, α to γ Aquilae, μ to η Geminorum.
1½° ,, ...	β to γ Arietis, ν to ξ Ursae Majoris.
1° ,, ...	Atlas to Electra Pleiadum. A half-penny (one inch) at 4 ft. 9 ins. distance.
½° ,, ...	Diameters of Sun and Moon. A half-penny at 9 ft. 6 ins.
5′ ,, ...	Pleione to Atlas Pleiadum.
3½′ ,, ...	ε^1 to ε^2 Lyrae.

Few unaided eyes are able to distinguish separately any two stars that are less than about 3′ apart. For details of smaller angles than this, necessarily appreciable only with a telescope, reference must

VIRGO. No. 29.



BOOTES
COMA BERENICES
LEO
LIBRA
CRATER
HYDRA
CORVUS
XV
XIV
XIII
XII
ARTHUR COTTAM F.R.A.S. delt
Epoch 1890
Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.6 6 6.5 Telescopic

be made to the tables giving the angular diameters of the planets and the separations of double stars. It will be recollected that $1° = 60'$, and $1' = 60''$. One minute of arc is the angle subtended by a half-penny at a distance of 95 yards. The same coin would have an apparent diameter of one second of arc at $3\frac{1}{4}$ miles.

* * * * * *

DIAMETER OF TELESCOPIC FIELD.

For estimating small angular distances, and for other purposes, it is often desirable to know the diameter of the field of view of different eye-pieces. This can easily be found by noting the time taken by an equatorial star in crossing centrally through the field. Since the Earth makes a complete rotation, through 360°, in 24 hours, it follows that a point on the Celestial Equator (which is a " great circle ") will appear to traverse an arc of 15° every hour, 15′ every minute, or 15″ every second. All that is necessary then, is to select some star that is on or very near the Equator (such as δ Orionis or ζ Virginis), and so point the telescope that the diurnal motion will carry it centrally across the field. The times of entry and exit are noted, and these give the interval required. If we multiply this interval, reckoned in minutes and seconds of *time*, by 15, we obtain the diameter of the field in minutes and seconds of *arc*. For example, if the time of transit were 1*m*. 3*s*. the diameter of the field would be 15′ 45″, and so on.

* * * * * *

NOTE :—Much of the tabular matter in this Section has been taken from the Handbook of the British Astronomical Association, by kind permission of the Council. The Tables giving particulars of the orbits of the planets are from the American Ephemeris.

PART IV.

PRACTICAL NOTES FOR THE AMATEUR.

I.

THREE FORMS OF MICROMETER, AND THEIR USE.

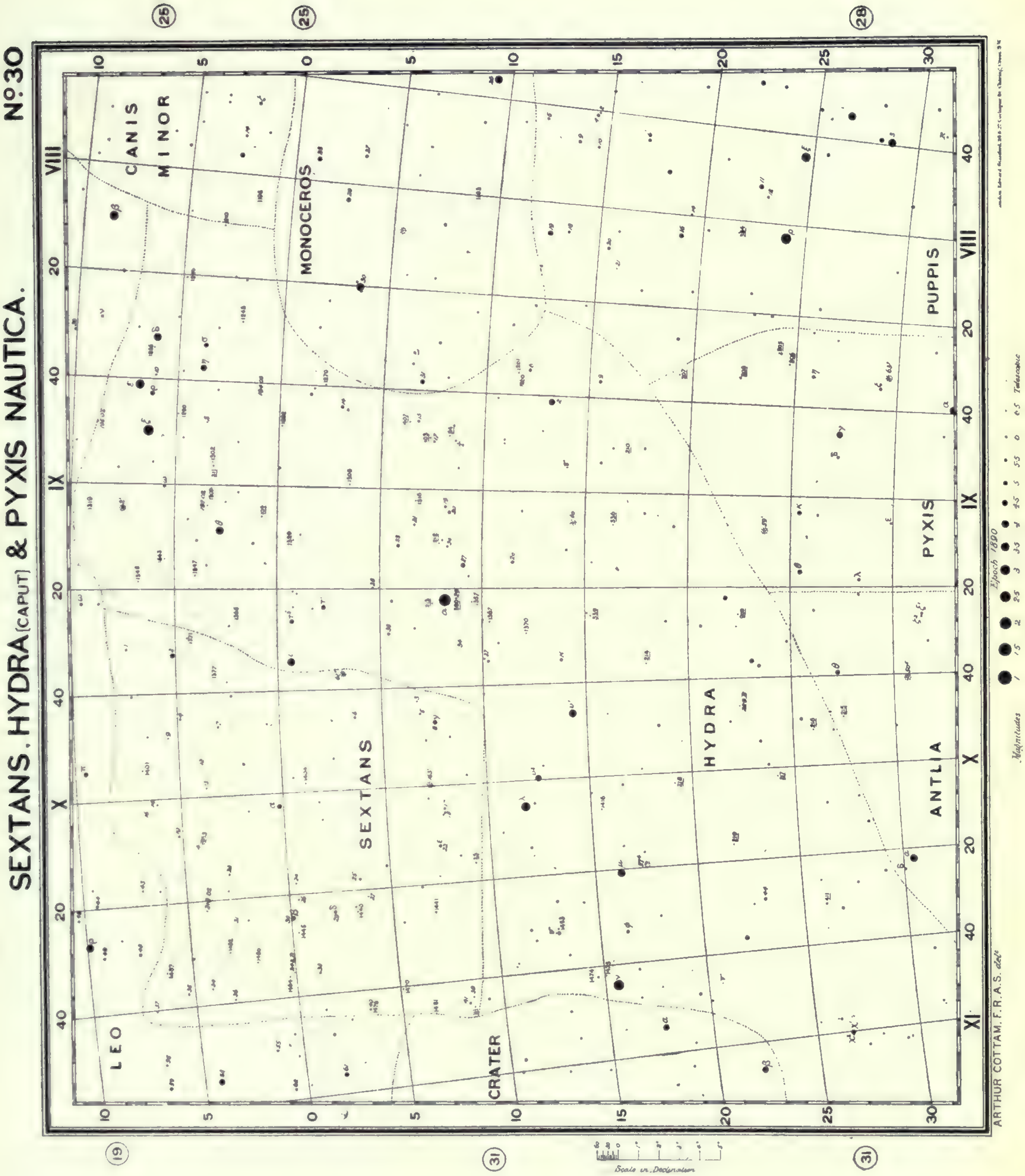
THE RING MICROMETER.

By A. C. D. CROMMELIN, B.A., D.Sc., F.R.A.S.

It is often useful for the observer to be able to measure the distance between some celestial object (comet, asteroid, new star, suspected variable) and a neighbouring known star; this distance must be found both in an East-and-West direction (Right Ascension) and in a North-and-South one (Declination). The Ring Micrometer, and the closely related Cross-Bar one, have many advantages for this purpose. They are simple and inexpensive, and involve no reading of screws; they can be used in a dark field, which is of importance in the case of faint comets. They need the use of some timepiece (not necessarily of very high quality, provided its error can be found somewhere near the time of observation) whose ticks are distinctly audible at the telescope. The Ring can be used with any form of mounting, but the Cross-Bar only on an equatorial.

The ring micrometer is simply a flat ring with both outer and inner edges circular, placed in the focal plane of the telescope.* One way of making it is to draw the design on a larger scale on paper, and reduce it by photography on a thin glass diaphragm, which is placed in the focal plane. Then we simply note the times at which the known and unknown bodies disappear and reappear at each side of the ring. The telescope must be so placed that neither body passes very near the centre of the ring. We must also note whether the bodies pass to the North or the South of the centre. A complete observation consists in noting the times at which the two objects pass the edges of the ring

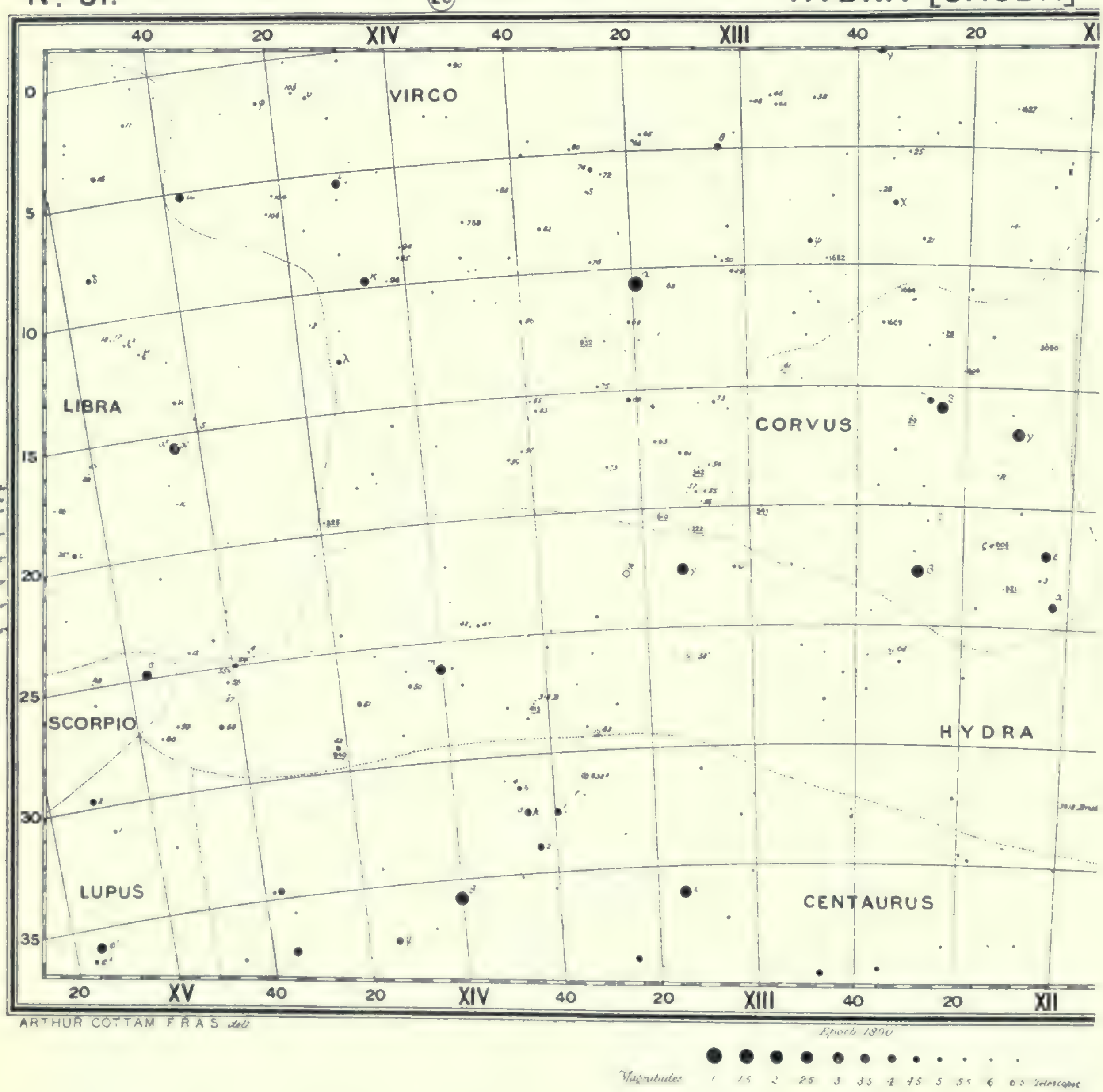
* In this case a positive eye-piece must be used. Where only a negative eye-piece is available the ring must be placed in the plane of the diaphragm between the two lenses, so as to appear sharply defined to the eye; but the results from such an arrangement will be less accurate owing to distortion by the field-lens. The same remarks apply to the Cross-Bar micrometer.


No. 30
SEXTANS, HYDRA (CAPUT) & PYXIS NAUTICA.
CANIS MINOR
MONOCEROS
PUPPIS
PYXIS
SEXTANS
HYDRA
ANTLIA
LEO
CRATER
Epoch 1890
Magnitudes
Scale in Declination
ARTHUR COTTAM. F.R.A.S. del.

(both outer and inner edges should be used if possible). The mean of the four times gives the time of the object crossing the central meridian SN. The difference of the times for the two objects gives the difference of their Right Ascensions. To find the Declinations we must observe a star near the equator a number of times and find how long it takes to cross the ring centrally. Suppose the time for the inside diameter is 40 seconds; this is equal to 10 minutes of arc or 600 seconds of arc. The time for any other declination is 40 seconds $\times$ the secant of the Declination. Find an angle q such that sine q = observed time from C to D $\div$ (40 seconds $\times$ secant decl.). Then OK = 600 seconds $\times$ cos q.

In the same way we find OL; the sum or difference of OK, OL gives the difference of Declination of the objects. The reason that the transits must not be near the centre of the ring is that in this position the difference of Declination cannot be accurately determined.

Nº 31. (29) **HYDRA [CAUDA]**



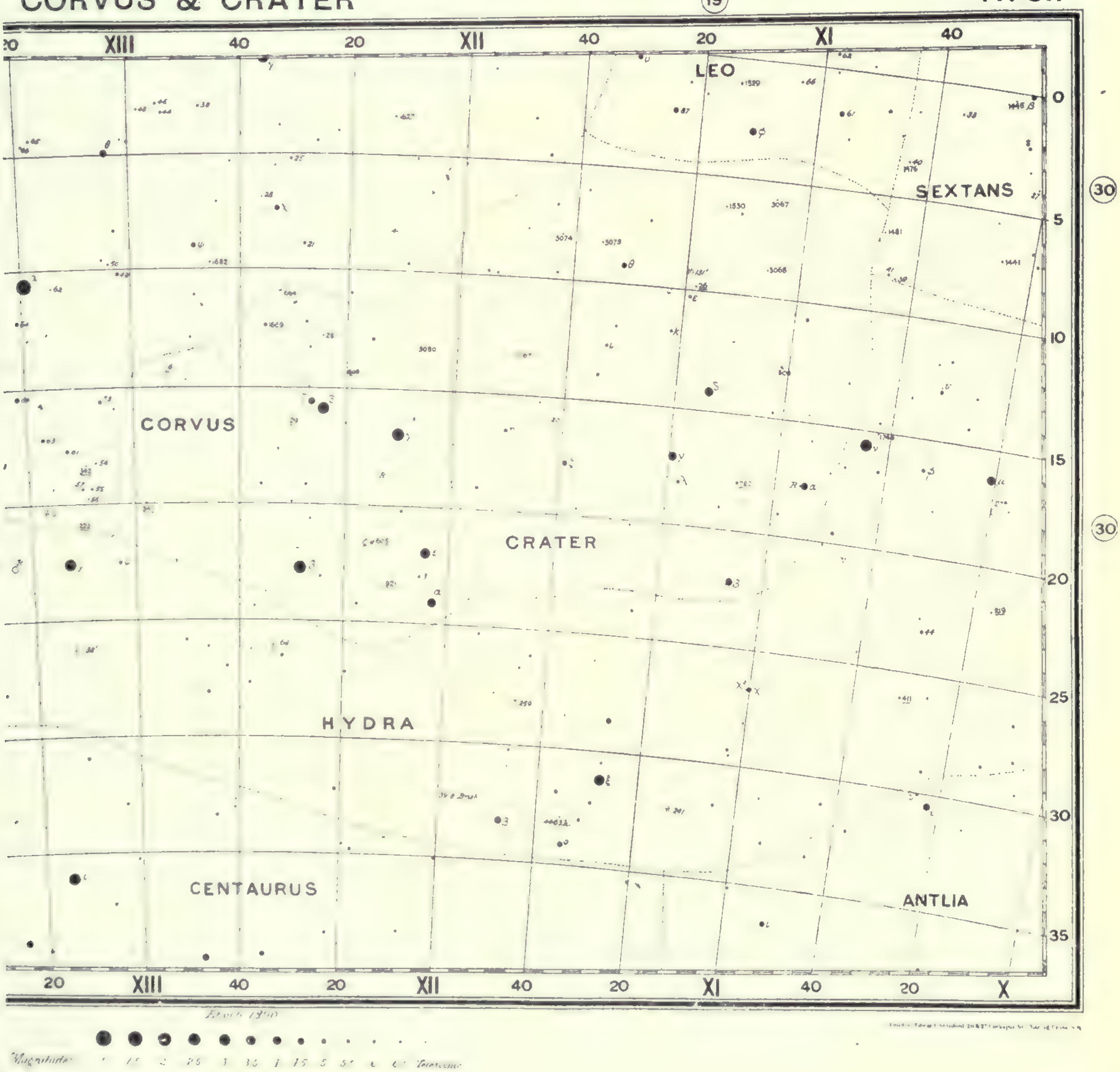
I work out an illustrative example. For simplicity I give only the times of crossing the inner edge of the ring; the method is precisely similar for the outer edge. As before, I take the time for an equatorial star to cross the inner ring as 40 seconds.

Let the times for the star be 7*h*. 13*m*. 5*s*. } mean 7*h*. 13*m*. 22*s*. (South of centre).
7*h*. 13*m*. 39*s*. }

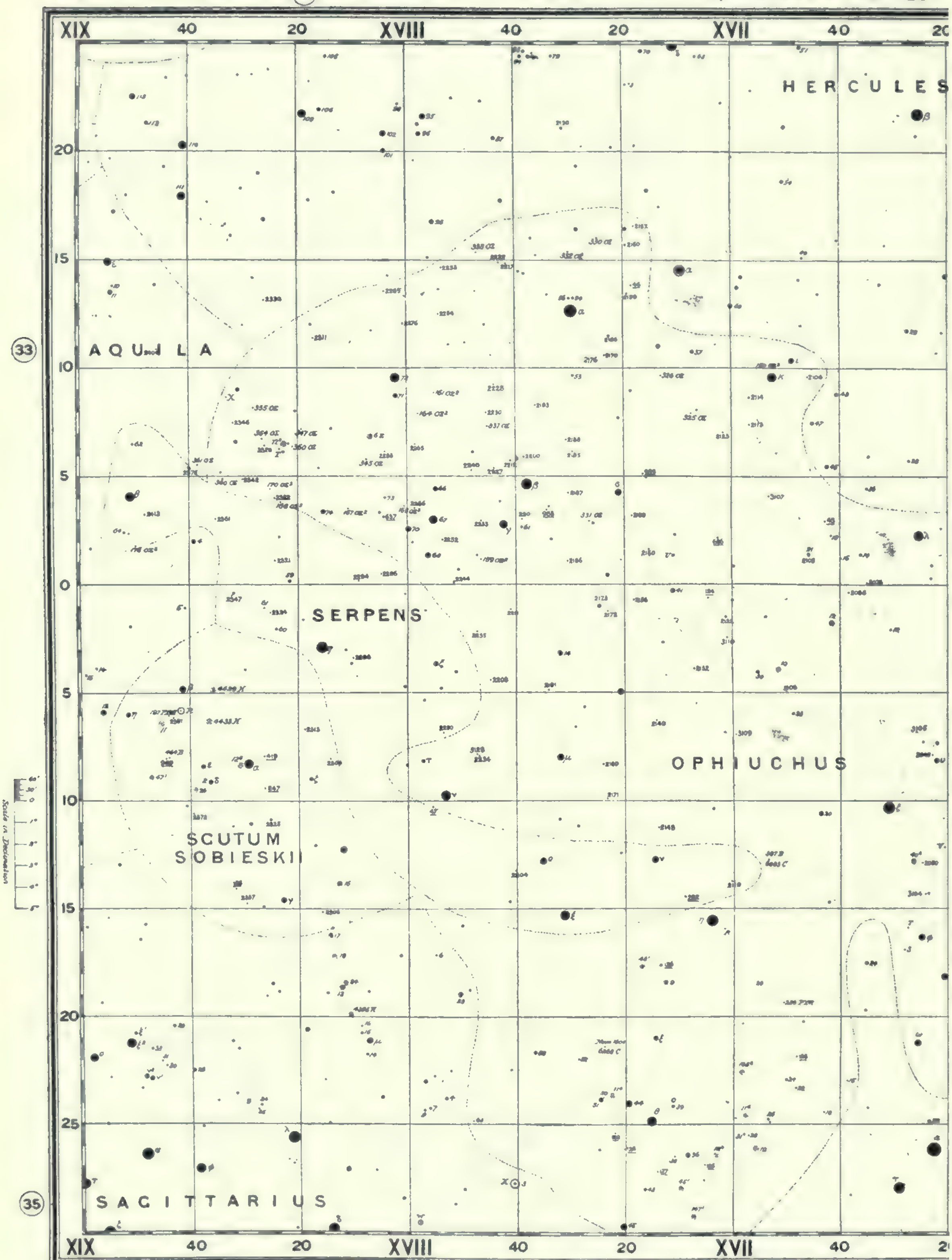
Let the times for the comet be 7*h*. 14*m*. 17*s*. } mean 7*h*. 14*m*. 31·5*s*. (North of centre).
7*h*. 14*m*. 46*s*. }

We see at once that the comet's R.A. is 1*m*. 9·5*s*. greater than the star's. If this is measured by a mean time clock, we increase it by 1 part in 365 or 0·2*s*., making it 1*m*. 9·7*s*. sidereal. Also the interval for the star is 34 sec., or 34·1 sec. sidereal. Let the star's Declination be 39° 43′, whose secant is 1·3000. Then the time for a central transit is 52 seconds. Log 34·1 = 1·5328, log 52 = 1·7160,

CORVUS & CRATER (19) No. 31.



No. 32. (21) OPHIUCHUS, SERPENS &



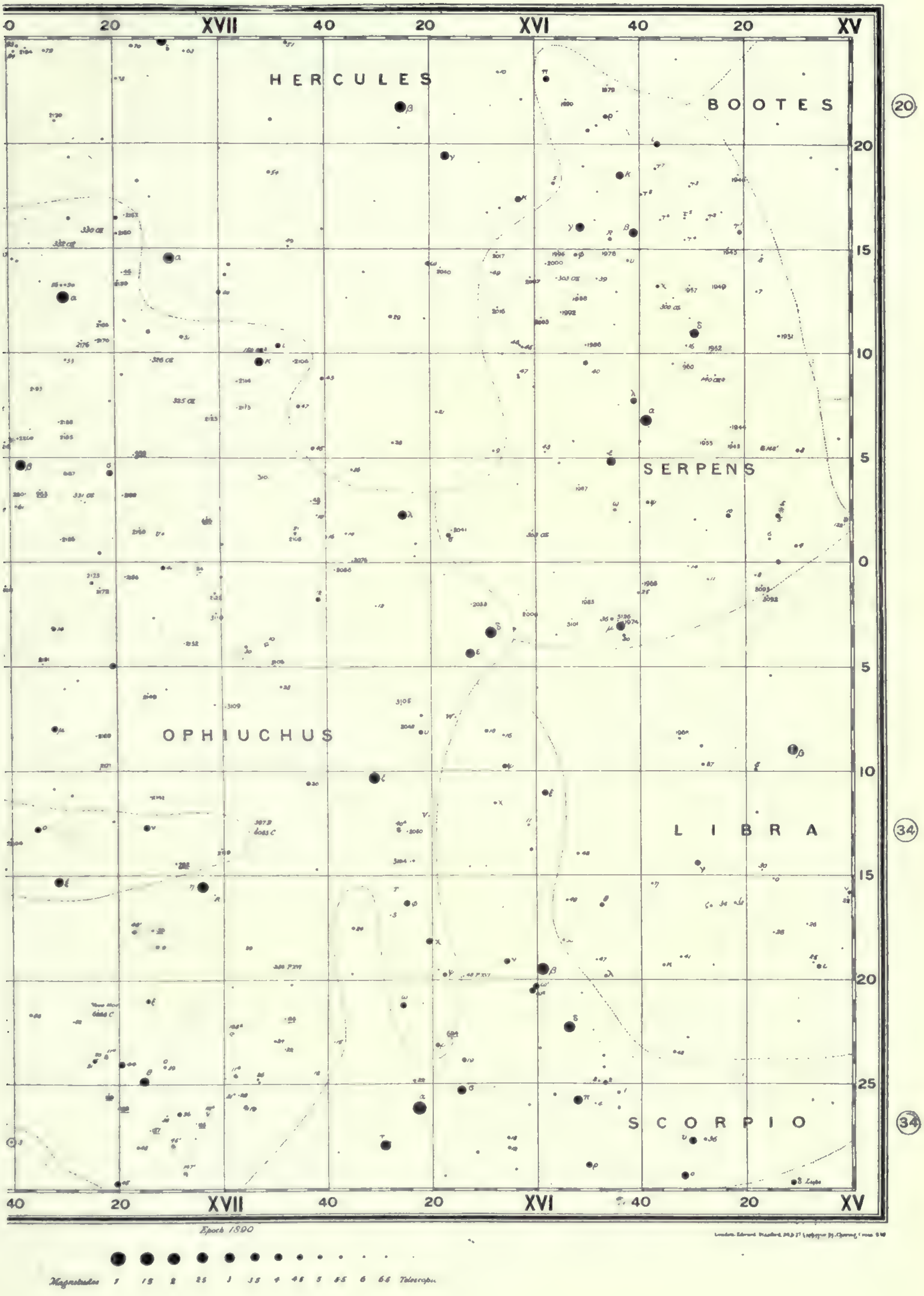
ARTHUR COTTAM, F.R.A.S. delt

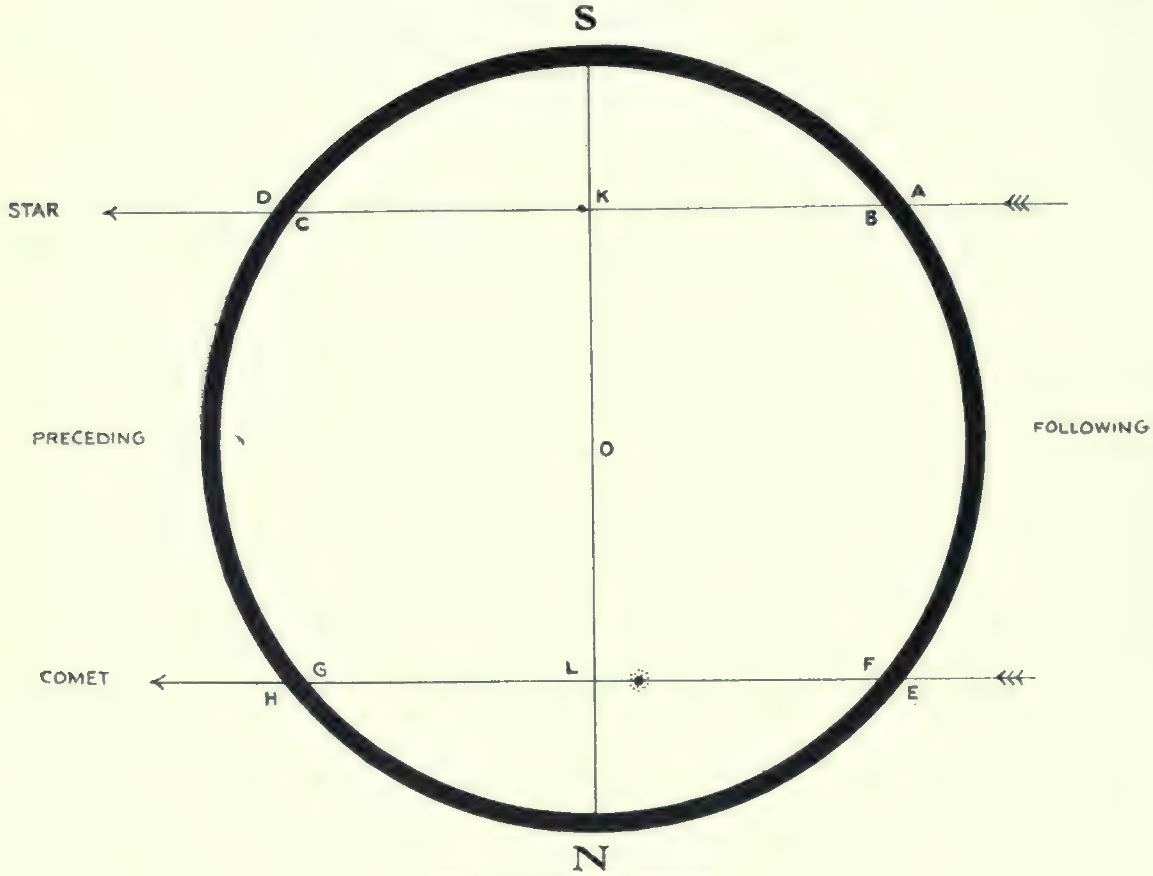
Epoch 1890

Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 Telescopic

SCUTUM SOBIESKII

No. 32.





THE RING MICROMETER.

log sin 40° 59′ = 9·8168 : log cos 40° 59′ = 9·8779 : log 600 = 2·7782 : whence log OK = 2·6561, OK = 453″.

To find OL we first treat the comet's Declination as equal to the star's: log 29·1 = 1·4626, log 52 = 1·7160, log sin 33° 55′ = 9·7466 : log cos 33° 55′ = 9·9190, log 600 = 2·7782, log OL = 2·6972, OL = 498″. Thus the comet is 453″ + 498″ = 15′ 51″ N. of the star, its Declination is 39° 58′ 51″; log secant = 0·1156, log 40 = 1·6021, log time of central transit = 1·7177. We get for the angle 33° 46′, for log cos 33° 46′, 9·9198, for log OL 2,6980, OL = 498″·9. We can avoid the second approximation by making a rough estimate of the comet's Declination before beginning the calculation.

I shall not attempt to describe the small corrections due to parallax, refraction and comet's motion; they can be made subsequently if the observer gives the necessary details.

The comparison star should be of the ninth magnitude or brighter, to ensure that it may be in some star catalogue. If the observer does not possess such catalogues, he should make a careful sketch of the faint stars in the field, and note the approximate position with regard to neighbouring naked-eye stars, by looking along the outside of the telescope tube. Several comparisons between comet and star should be made; the telescope must remain absolutely at rest during each comparison; it is, of course, moved between them.

We may, at a pinch, use the boundary of the field of view of the eyepiece as a ring micrometer, finding its diameter by letting an equatorial star cross it centrally several times and noting the number of seconds required.

It is well if possible to note some faint stars that enter the field a little before each object, so as to have warning of its approach.

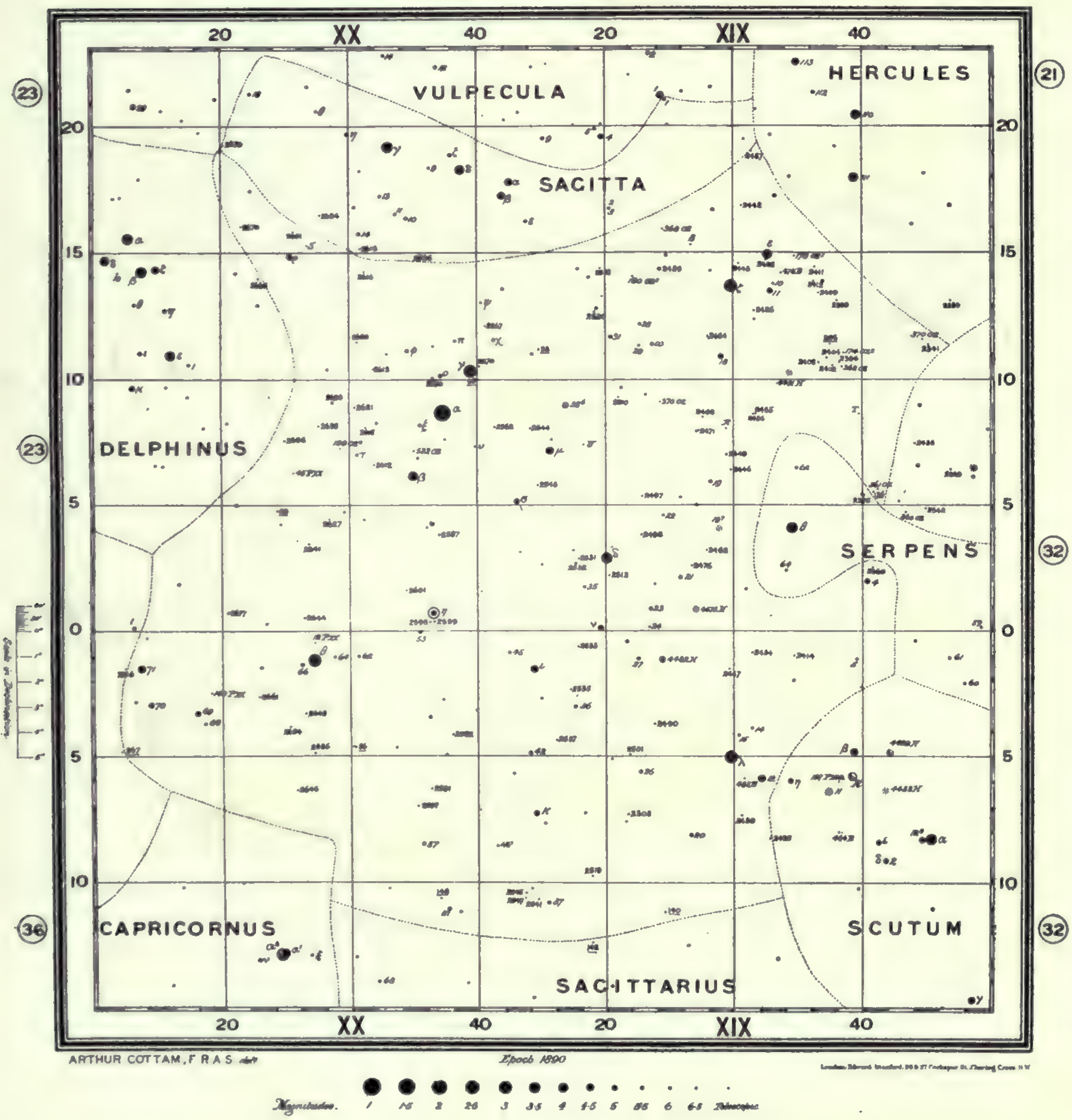
In observing faint comets the eye will not bear any artificial light, so a second must be taken from the clock beforehand, and the count continued carefully by listening to its beats. A very dim lantern, with a red shade, may be used to throw enough light on the note book to let the times be entered. The approximate error of the clock should be noted, as we require to know the true time of the observation of a comet, or of any object that is in motion.

THE CROSS-BAR MICROMETER.

By A. C. D. Crommelin, B.A., D.Sc., F.R.A.S.

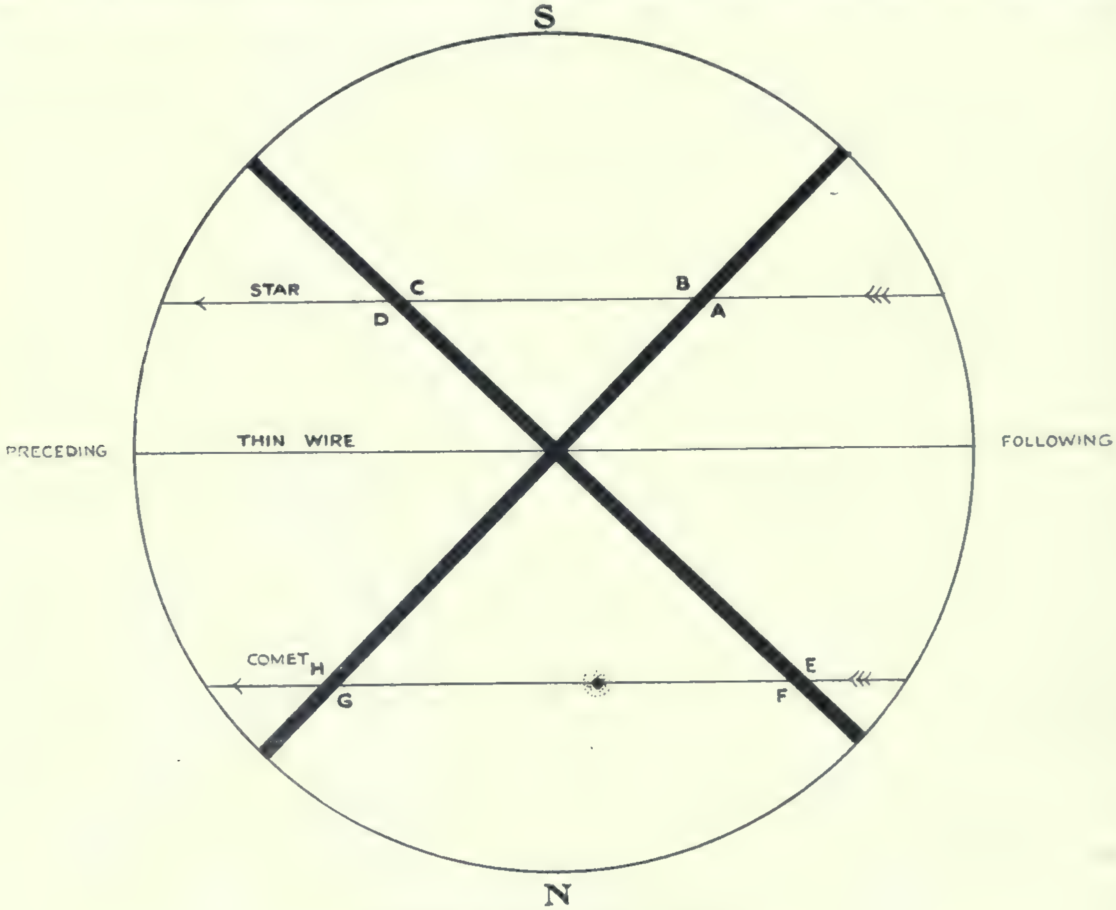
There is much in common between this and the Ring Micrometer. The reductions with the Cross-bar are simpler, but it is only possible to use it with an equatorial, so that with other mountings

AQUILA & ANTINOUS. No. 33.

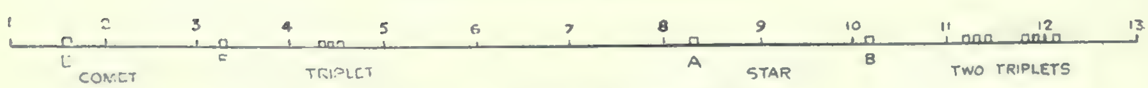


we should use the ring. The reason of this is that the Cross-bar needs to be set in a particular position, with its two bars, which are at right angles, each inclined 45° to the East and West line. With a non-equatorial mounting it would deviate appreciably from this position in a few minutes, whereas the ring is always in adjustment. On the other hand, the reduction for Declination is simpler with the Cross-bar.

In some cases the frame carrying the cross-bars is attached to a position circle; in this case we adjust it by making a heavenly body run along the edge of one of the bars, and then turning



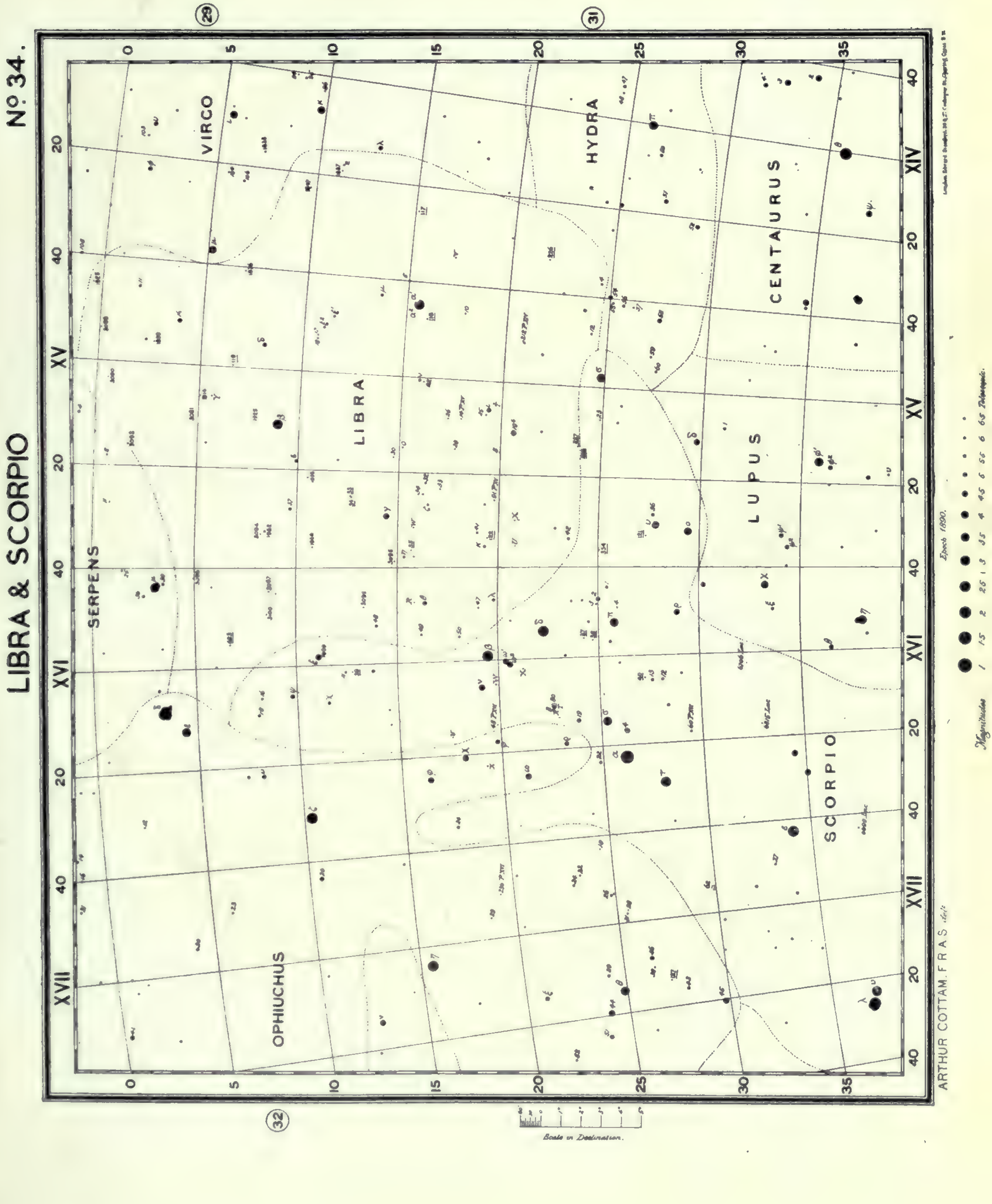
THE CROSS-BAR MICROMETER.



SPECIMEN OF CHRONOGRAPH RECORD.

through 45°. In other cases we need a thinner wire bisecting the angle between the bars; we make a star run along this wire. Once the correct position is found it should be marked in some manner, so as not to take time in setting on each occasion. Also, to guard against wrong setting, we should select if possible a comparison star that is very nearly on the same parallel of Declination as the comet. If this is not possible, it is well to have two comparison stars, one North of the comet, the other South. If the two stars are both observed in the same position of the telescope, we are able to deduce how much the orientation of the bars is in error, and apply a correction.

The method of observing is similar to that with the ring micrometer. We note the times of the


No. 34.
LIBRA & SCORPIO
VIRGO
HYDRA
CENTAURUS
LIBRA
SERPENS
LUPUS
SCORPIO
OPHIUCHUS
ARTHUR COTTAM, F.R.A.S.
Epoch 1890.
Magnitudes
Scale in Declination.

objects passing the points ABCD, EFGH, and take the mean of the four in each case ; the difference of these means gives the difference in Right Ascension. Also, take the mean of AB and of CD. The difference of these means in seconds of time multiplied by seven and a half cosine Declination gives the distance of the star South (or North) of the centre of the field. We go through the same process for the comet, using an approximate Declination, and correcting if necessary by using the Declination thus found in a second approximation. I do not give the method of correcting the observations for refraction, parallax, etc. I refer the reader to a paper by Colonel Tupman in Monthly Notices, R.A.S., for January, 1888. The reader with a little mathematical knowledge will readily be able to deduce corresponding formulae for the ring micrometer.

However, if the observer feels unable to deal with these corrections, it will suffice if he gives full details of the times of the objects crossing the bars ; the corrections can be applied by those who deal with the observations. I may add in conclusion that if the observer can procure a chronograph of any form it will greatly conduce both to the ease and accuracy with which the observations are made ; it will no longer be necessary to continue a long count of seconds. An arbitrary mark made at a particular beat of the clock will enable the seconds on the chronograph record to be identified. I follow the plan of sending a triplet of warning taps after the comet has crossed either bar, and two triplets after the star has crossed it. These are shown in the sketch, the figures 1, 2, 3, etc., being the clock taps ; they are a help in reading the record.

In such a series of observations the comet's Right Ascension and Declination can generally be seen to alter appreciably from one set to another. A rate of four minutes of R.A. a day means a second in six minutes ; and comets often move much more rapidly than this.

THE BI-FILAR (OR PARALLEL-WIRE) MICROMETER.

By Rev. T. E. R. Phillips, M.A., F.R.A.S.

Of the various forms of micrometer used for the measurement of small quantities in Astronomical observation, that known as the filar micrometer is the one most generally employed. Especially is this the case in the measurement of such objects as double stars, the diameters of the planets, and the surface features of the planets and the Moon. A reference to this form of instrument, with a diagram of the field, is given on page 517 and an illustration of the instrument itself on page 719, but some notes are added here which may be of practical use to amateurs who feel inclined to take up this branch of Astronomical observation.

As shown on page 517, the field of the micrometer contains two sets of webs (spider webs) at right angles to each other. One set, which may be either two parallel webs close together, or a single web (which is really sufficient), cannot be moved except by rotating the micrometer box, for which purpose a pinion motion is provided. The direction of this set of webs is indicated by the reading of a circle divided into 360°, known as the *position circle*, and the micrometer is so adjusted in the telescope that when the indexes of the circle read 90° and 270°, a star—the driving clock being stopped—traverses the field parallel to the webs concerned. The angle, known as the " Position Angle," or " P.A.," is accordingly measured from North (zero) through East (90°) throughout the 360 degrees.

In adjusting the micrometer in the telescope tube by observing the passage of a star, the eyepiece with the largest field should be used, and the instrument, when adjusted, securely clamped. If the adjustment is then found to be not quite perfect, the reading of the position circle when a star travels along one of the webs, or evenly between them, should be noted, and the difference from the direction 90°–270° applied as a correction to the subsequent measures.

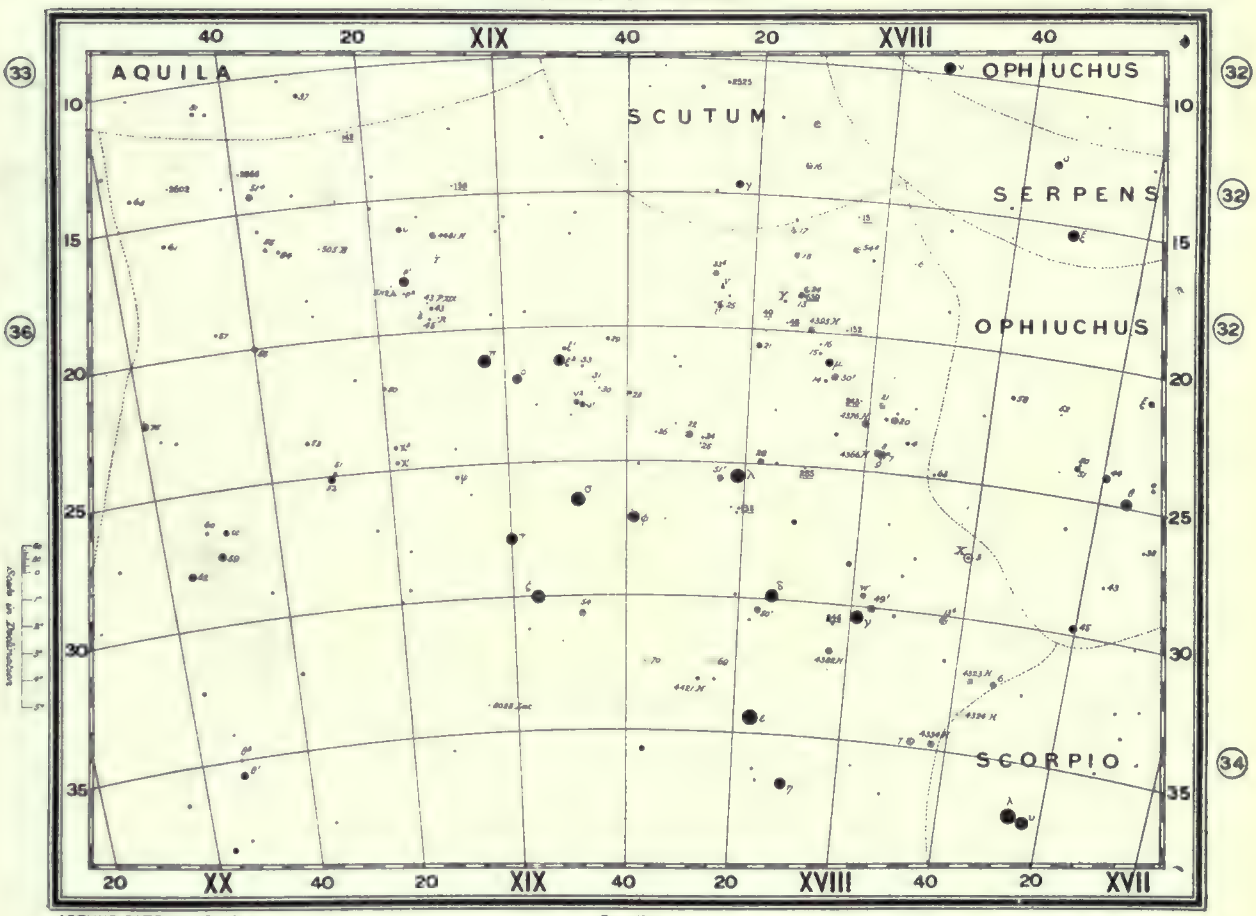
The webs at right angles to the position webs are used for the measurement of " *distance*," or the interval between two points as seen projected on the background of the sky. They are two in number, and they are both movable by screws so that they can pass each other, and it is important that they should be so nearly in the same plane that they can be seen in good focus together with the highest power eyepiece used. Commonly each screw is provided with a graduated head with 100 divisions,

the heads themselves being just friction tight to allow for necessary adjustment, so that when the two webs are superposed their indexes may read zero. As a matter of fact, it is sufficient if only one of the screws is provided with a graduated head (*see* illustration on page 719), since the other web is not moved after it has been once adjusted and is known as the " fixed " web. Its use will be explained presently.

In order that the two sets of webs may be seen at night, some means of illumination is necessary. For this purpose small electric lamps are fitted, and they are arranged so that either the field itself may be suitably illuminated, in which case the webs are seen as dark lines against a bright background, or light is thrown upon the webs themselves so that they appear as bright threads against the dark sky. This latter arrangement is, of course, the more suitable one when measuring faint objects, but for bright objects an illuminated field is preferable. It is desirable to include in the equipment some form of variable resistance for regulating the intensity of the light.

The interval, as measured directly by the distance webs, is, of course, expressed in terms of a revolution of the screw, some arrangement being provided for showing the number of complete revolutions as well as its fractions. Since, however, what is required is the *angular* separation of the webs, the value of a revolution in *seconds of arc* must be accurately determined. There are two methods of doing this. One is by making use of widely separated pairs of stars, showing little or no relative

SACITTARIUS. No. 35.



ARTHUR COTTAM, F.R.A.S. delt Epoch 1890

Magnitudes 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 Telescopic

motion, whose angular separation or difference in Declination is known. The distance, as measured by the readings of the divided screwhead, is determined by the method to be described presently for the measurement of double stars (except that when the *difference in Declination* is to be utilised the position webs must be set to read 0°–180°), and then, since the interval in seconds of arc is known, the value in angular measure of one complete revolution of the screw is readily deduced. The following pairs of stars in the Pleiades are suggested as suitable for the purpose in hand:—

Electra and Celaeno	Difference in Declination	**633·40″**
Atlas and Pleione	,, ,, ,,	**300·25″**

In the case of very widely separated stars of different Declination or altitude, it is, of course, necessary to correct their places for refraction.

The other method, which is for various reasons more convenient, is to set the position webs to read 90°–270°, stop the driving clock, and observe a star of high Declination on or near the meridian drift across the field of view. The position of the movable web when placed well on the *following* side of the centre is read before the star enters the field and the time of its transit of the web noted to the nearest tenth of a second by the beats of the clock or by a stop-watch. Immediately after the transit, the web is moved forward in advance of the star a number of complete revolutions of the screw, and the time of the second transit of the star observed. These observations are repeated a large number of times and the mean interval between the transits in seconds of sidereal time deduced. If the star be close to the pole its path across the field will show a distinct curvature, and a somewhat elaborate formula will be required for the reduction to angular measure. If, however, a star be chosen such that, while its Declination is sufficiently high for its motion to be slow, its path is yet sensibly parallel to or along one of the position webs, the following simple formula—where R″ is the value of a revolution of the screw in seconds of arc, t is the mean interval in sidereal seconds between the transits, δ is the Declination of the star, and n the number of revolutions of the screw between the two positions of the webs—will be quite sufficiently accurate:—

$$R'' = \frac{t \times \cos\delta \times 15}{n}$$

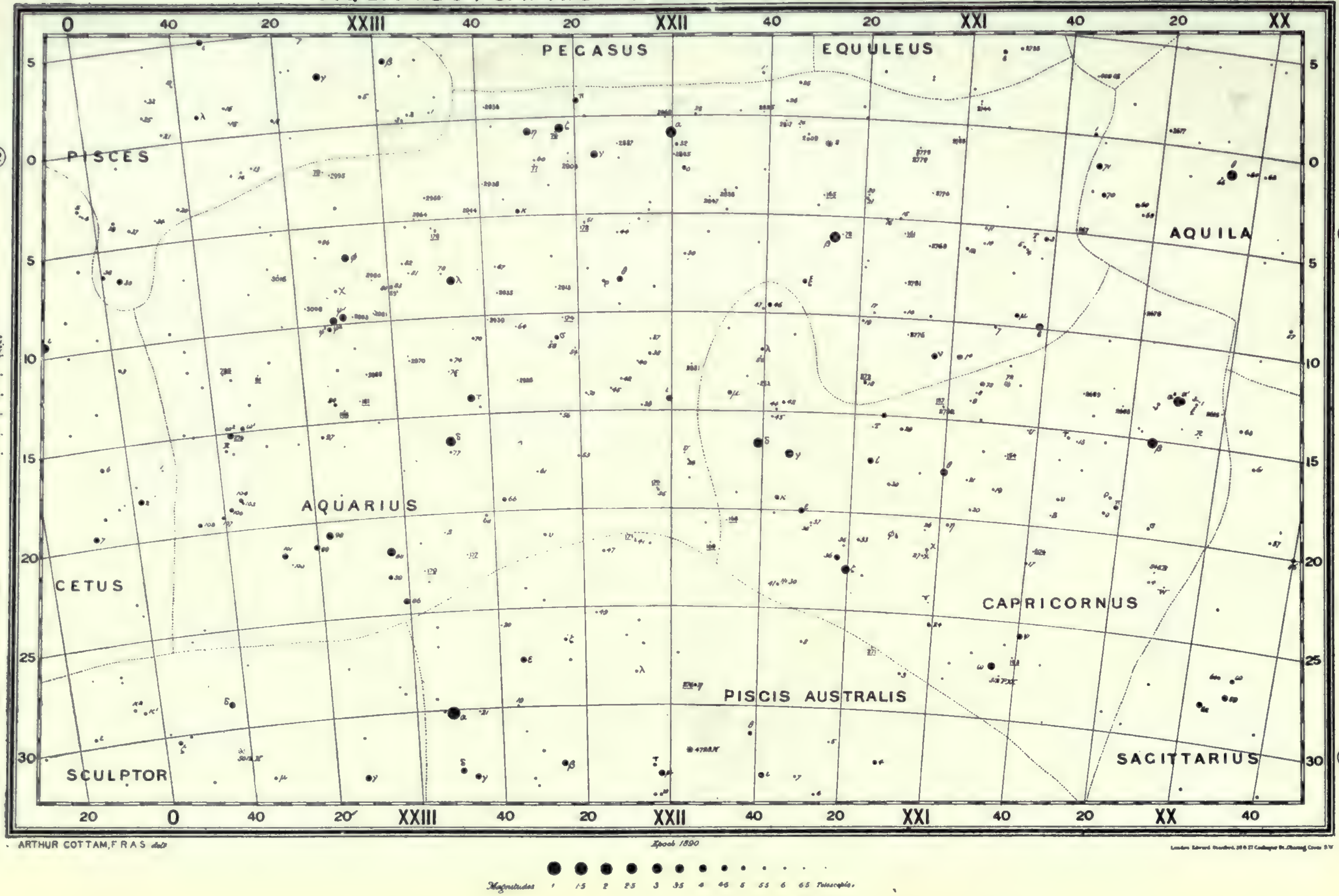
A table giving the value of fractions of a revolution can then be prepared for use in the conversion of the micrometer readings in double star or other measurements to angular separation.

In the measurement of double stars two things have to be determined: First the direction of the line between the two components, termed the "position angle," and, secondly, their angular separation or "distance." For the former the position webs are used, the micrometer box being turned by the pinion so that the two star images are between them and equally distant from both, or else one of the webs is made to bisect the two star images. In large and heavy Equatorials there is a provision for moving the whole micrometer box, so as to bring the star to the desired position in the field, but in smaller instruments the telescope itself is moved by the slow motions. Several settings—say four or more—are made, and the mean of the readings taken.

For the angular separation the "distance" webs are used. The "fixed" web is made, by adjusting the telescope (or moving the micrometer box), to bisect one of the stars, and the second web is moved back by the screw till it is well outside the other star and then moved forward again till the latter is bisected by it. This operation is repeated a number of times—say three or four—care being taken (a) to see that at each setting the fixed web is bisecting its star, and (b) to bring the movable web up to the star it is to bisect always *from the same direction*, so as to avoid any error arising from slackness or backlash in the screw. The mean of the readings is then taken, but it will be clear that this does not accurately represent the separation of the two stars unless the index of the divided screwhead reads exactly zero when the two webs are coincident. Any error, however, due to imperfect adjustment (zero error) is completely eliminated by the "double distance" method, which should always be adopted and which is as follows: The measures just described having been completed, the "fixed" web is made to bisect the image of the second star, and the movable web is moved across to the other side

AQUARIUS, CAPRICORNUS & PISCIS AUSTRALIS.

Nº 36.



ARTHUR COTTAM, F.R.A.S. del.

Epoch 1890

and made to bisect the first star. The same number of settings is taken as before, and it will be clear that the difference between the mean readings of the two sets of measures gives double the distance between the stars. Half the measured distance is then converted into seconds of arc by reference to the table already computed, and the operation is complete and quite free from any effect of zero error. It is desirable to repeat the measures on *at least* two other nights, especially in the case of close pairs, or if the conditions of seeing have been only second rate.

Measures made with the filar micrometer are liable to be affected by certain systematic and other errors, which should be carefully investigated and guarded against. It is found, *e.g.*, in the case of double stars, that unless special precautions are taken, measures of the same pair will yield discordant values of the position angle when it is at a distance from the meridian and on opposite sides of it. There is clearly an error depending on the varying orientation of the pair in the course of its diurnal motion; and to avoid this it is important to ensure that the line between the two stars is either parallel to, or perpendicular to, the line between the observer's eyes.

When the components of a double star differ considerably in magnitude, errors in setting for position angle are also liable to occur. Owing to diffraction effects, it is not always easy to be sure that both discs are accurately bisected, and if the web is displaced slightly, the line between the stars may not appear parallel to it on both sides. In such cases the writer puts the stars alternately on opposite sides of the web and adjusts the latter until the apparent departures from parallelism are opposite and equal.

There is one curious effect which the writer of this note and others have very occasionally experienced, viz., a regular progression (either of increase or decrease) in the measures of the position angle of a star to the extent of some degrees. These " runs " are hard to explain. Care is taken to move the web right away from the companion before each setting and to bring it up to the star from opposite sides, and yet there is a progressive change which may persist for perhaps as many as half-a-dozen settings ! In these cases it is the writer's plan to go on with the measures till the run ceases. Further settings may then make it almost certain that the earlier values were for some unknown reason erroneous, in which case it might be felt necessary to reject them, or to continue the settings so long that the effect of the supposed error is largely eliminated in the mean. But one rightly hesitates to reject altogether measures which have been carefully made merely because they are discordant, unless there are very strong grounds for doing so.

As regards measures of distance, a difficulty arises when the stars are very close. If the webs are set *on* the stars the light spreads out on either side from behind them, and it is impossible to feel sure that they are correctly placed. In these cases the writer often puts the webs by *the side of*, and not *on*, the close pair, and adjusts them to the correct distance by estimation. With an eight-inch Cooke refractor the necessity for this procedure appears to arise when the stars are appreciably below one second of arc apart, although the magnitudes of the stars also affect the case.

Besides the difficulties already mentioned, there are errors connected with the " personal equation " of the observer, which the computer of double star orbits needs to investigate and allow for in making use of published measures. But these need not be considered here.

Perhaps one of the most difficult, or at any rate one of the most unsatisfactory, kinds of object to measure with the filar micrometer is the Snow Cap on Mars. When quite small it is not practicable to set the webs on it, and if they be set by the side of it and adjusted by estimation, there is apparently a very large error (this is not apparent in the case of two bright dots like double stars) which may perhaps vary with the personal equation of the observer. Professor W. H. Pickering found some years ago by such measurements of small illuminated holes, viewed from a distance through the telescope, that it was necessary to increase his results as measured by about one-third of their value! The writer's measures of the polar caps also make the diameter very considerably smaller than the corresponding values deduced from drawings, but, on the other hand, as regards the latter, the eye, in estimating the size of the white spot, may well, and probably does, err in the opposite direction and make the cap too large. The subject is an interesting one and further investigations of the problem

would be of value. Amongst other things, it seems especially desirable to find out what is the exact nature of the relationship of the error described to the angular dimensions of the polar cap. The reason for the error is not apparent, since measures of the discs of the planets (which, however, are made with the webs tangent to the limb) have a tendency to come out *too large* as a result of irradiation.

It is generally agreed by observers that the refractor is far better suited to micrometrical work—at any rate on double stars—than the reflector, owing to its relatively greater focal length, and the fact that its images of stars are almost invariably neater and much less blurred by atmospheric disturbances. It is true that the Rev. T. H. E. C. Espin has for many years been carrying out at his observatory at Tow Law, in Durham, a very extended and extremely successful programme of double star measurements with large reflectors of twenty-four and seventeen and a quarter inches aperture, but he is an outstanding exception, and observers who have had experience of both classes of instrument are apparently almost unanimous in their conviction that, while the reflector has its undoubted advantages for certain classes of work, for use with the micrometer, preference must be given to the refractor. With both classes of instrument it will often be found advantageous to increase the focal length by the use of a Barlow lens. High magnification can then be obtained without employing high power eyepieces, which mean an uncomfortable magnification of the spider webs and increase the difficulties of observation and the probabilities of error in the results.

II.

THE SPECTROSCOPE IN THE HANDS OF THE AMATEUR.

By W. Alfred Parr, F.R.A.S.

In the first chapter of this work which, appropriately enough, begins with the Story of Light and Man's Control of It, Dr. W. H. Steavenson has dealt with the main principles underlying the science of spectroscopy, while in the course of a subsequent chapter, Mr. C. P. Butler has shown, on page 154, how the spectroscope has enabled us to analyse the atmosphere of the sun. At a still later stage in our proceedings, Mr. Herbert Dingle has devoted Chapter XII to a spectroscopic interpretation of the Message of Starlight, so that the reader of these articles may be assumed to be in possession of the main facts concerning the methods and aims of the great new department of astronomy known as Astrophysics. But the description of the highly specialised instruments with which some of the more striking results are obtained, as well as the delicacy of the observations themselves, to say nothing of the elusive nature of the phenomena observed, may possibly lead him to suppose that, in this department at any rate, the amateur will find but little scope for his activities. That this is by no means necessarily the case it is the object of the following short article to prove.

In the case of stellar spectroscopy, where the source of light is at best a feeble one, it is true enough that ample instrumental means must possess an advantage over small ones ; but with no more elaborate outfit than a three-inch altazimuth refractor, fitted with a small star-spectroscope, it is quite possible to master some of the leading distinctions in the science which has fitly been termed the " language of the heavens." Indeed, as was pointed out by Professor Fowler in his series of papers on the " Chemistry of the Stars," contributed to *Knowledge*, in 1903, the epoch-making discoveries of Fraunhofer were secured with a telescope only a little over an inch in aperture ! Perhaps the most suitable instrument for the amateur's purpose is the Zöllner star-spectroscope. This inexpensive piece of apparatus consists of a simple combination of three prisms and a cylindrical lens, mounted in such a manner as to fit over the usual astronomical eyepiece—preferably one of low power—like an ordinary sun-cap. After sharply focussing the star in the telescope, the Zöllner is screwed on to the eyepiece, when the star's image will be found to be transformed from a point of light into a coloured band, crossed at intervals by the distinctive lines which constitute the " signature " of the particular star under observation. It will be noted that a slit forms no part of this simple apparatus, the spectrum appearance being produced by the combined action of the

prisms, which disperse the stellar point into a coloured line, and the cylindrical lens, which broadens this line into the familiar coloured band. Provided with this modest addition to his telescope, the amateur will find his interest in the stars at once deepened and broadened, for, to quote the late Professor Keeler, " the light which reveals to us the existence of the heavenly bodies also bears the secret of their constitution and physical condition." Thus the main features of stellar spectroscopy in its broadest outlines, as set forth on page 486 of this work, can easily be followed with the means just described, though the amateur should bear in mind that Secchi's classification relates to the visual spectrum, with which we are here more immediately concerned, while the Draper notation refers rather to the photographic method of observation. For our particular purpose, those spectra in which the hydrogen lines $H\beta$ and $H\gamma$ are prominent, as in the case of Sirius and Vega, will perhaps be the easiest of observation, but the most beautiful in a small instrument are undoubtedly the banded spectra yielded by such stars as Betelgeuse and α Herculis, where the absorption bands exhibit the most delicately pencilled flutings. Certainly no more absorbing study can be imagined than such an enquiry, elementary though it may be, into the main characteristics of stellar spectroscopy. But the amateur who takes a pride in his work will not rest content merely to *enjoy* what Henri de Regnier has called " le plaisir délicieux et toujours nouveau d'une occupation inutile,"—he will most assuredly wish to make these fascinating observations of real use to science as well, and a method of doing this was outlined by Mr. Harold Thomson, F.R.A.S., in his presidential address to the British Astronomical Association in October, 1919. When Nova Aquilae III was ablaze in the summer-night skies of 1918 the spectrum it then yielded was by far the most magnificent the writer had ever witnessed, though observed with only a small refractor in combination with a Zöllner spectroscope. An outburst of this kind serves to bring new recruits to the ranks of astronomers—two of the greatest, Hipparchus and Tycho Brahé, were summoned by a new star—and presses home the importance of the systematic observation of variable stars in general and of novae in particular. Thus, in connection with the wonderful apparition of 1918, Mr. Harold Thomson threw out the suggestion that variable star observers should make a practice of sweeping along the Milky Way and of examining any strongly coloured star with a small slitless spectroscope attached to a low-power eyepiece. In this way a nova, if near its maximum,

Photo by] [*W. Alfred Parr.*

3-INCH ALTAZIMUTH REFRACTOR BY STEWARD,

fitted with transmission grating prominence spectroscope by Hilger. Note the small view-telescope set at an angle to the spectroscope, giving an enlarged view of the red end of the spectrum.

would betray itself by its characteristic bright-line spectrum. The writer would further suggest that a convenient way of carrying out a search of this kind is to use on the telescope a double nose-piece fitted with two low-power eyepieces, to one of which the Zöllner is permanently attached. It is then easy to arrange the draw-tubes of the nose-piece in such a manner that either eyepiece is sharply focussed when switched into position.

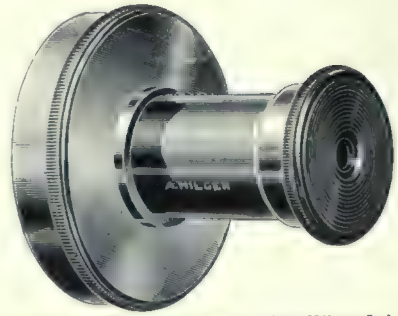
In stellar spectroscopy the question of sufficient light is an urgent one, affecting the amateur's chances of success in direct proportion to the aperture he commands, but in the case of solar spectroscopy the conditions are much more in his favour. Here there is a superabundance of light available, and it is precisely in this department that a moderately-sized telescope becomes a really efficient weapon of research. In a lecture delivered before the Royal Astronomical Society in 1907, Professor George E. Hale goes so far as to say that "for a study of the general characteristics of the solar prominences the small instrument has even a great advantage over the large one." These are comforting words indeed for the amateur, coming as they do from one who has worked with the greatest refractor in the world, and Professor Hale goes on to show that an instrument like the forty-inch Yerkes telescope is wholly unsuited for work of this kind, as the images of the prominences formed by it are usually far too large to be included within the slit of the spectroscope without admitting too much general light from the sky. He then suggests as "*an almost ideal equipment*" a telescope of about four inches aperture, used in conjunction with a small, but suitable, spectroscope. Another great authority on Solar Physics, the late Charles A. Young, says on page 192 of his classic work, "The Sun," that "with a telescope of not less than four inches aperture, equatorially mounted, and a spectroscope of [sufficient] dispersive power . . . the observer is equipped for the study of the chromosphere and prominences."

Photo by] [*W. Alfred Parr.*

4-INCH PHOTO-VISUAL CLOCK-DRIVEN EQUATORIAL REFRACTOR BY COOKE, with modified Evershed prominence spectroscope (two prism type) by Hilger. Note the light canvas shelter which can be placed over the equatorial mount and closed with removable door when the telescope is dismounted.

As regards elaboration of outfit, however, it was pointed out by the late Colonel (then Captain) Tupman, at a meeting of the Royal Astronomical Society so long ago as 1872, that a three-inch altazimuth refractor, used in combination with a Browning direct-vision spectroscope, represented an adequate equipment for viewing the prominences as such; while some years ago the writer contributed a paper to the *Journal* of the British Astronomical Association giving an account, illustrated with drawings, of his own observations, also made with a three-inch altazimuth to which was attached a transmission grating spectroscope, made especially for the purpose by Hilger. This little instrument, which has proved extremely efficient, contains a film replica grating of 14,438 lines to the inch, and is provided with an adjustable slit, which is protected from dust by a glass window so that the spectrum given is exceedingly "clean" and free from dust-lines. A small view-telescope is added which is set at such

an angle that the orange and yellow portions of the spectrum only, from just below λ6563 to a little above λ5876, appear in the centre of the field. This addition gives an enlarged view of the region lying near and between those lines which offer the greatest interest for visual work upon the Sun, viz., C and D. The view-telescope, however, is by no means a necessary adjunct to the outfit, and may be dispensed with altogether. Attaching, then, the spectroscope to the refractor (from which the eyepiece has been removed) and arranging matters so that the image of the Sun formed by the object-glass is sharply focussed upon the nearly-closed slit, the solar spectrum crossed by hundreds and hundreds of the exquisitely fine dark Fraunhofer lines will be seen spread out in all its pageantry of gorgeous colour. This in itself is an interesting and beautiful spectacle from which much may be learned, but if, now, the telescope be so manipulated as to place the slit tangential to the solar limb, the strong dark C line at λ6563 in the orange-red will be seen brightly reversed for part of its length, as will also the fine line D_3 in the orange-yellow, indicating respectively the glowing hydrogen and helium existing in the chromosphere. On slowly rotating the whole spectroscope, taking care to keep the slit constantly tangential to the Sun's limb, certain brilliant notches may be observed on the C line in some positions of the instrument, betraying at these particular points the presence of prominences, and, if then the slit be cautiously opened, the entire form of the prominence in question may be seen. The Fraunhofer lines themselves, being merely the dispersed images of the slit, will of necessity become diffused and indistinct as soon as the latter is opened. The simple operation described completes what the late Miss Agnes Clerke used to call the "task of daily promenading the slit round the solar limb," which, if systematically performed and duly recorded, constitutes a valuable survey of the entire ring of prominences visible on any sunny day. As the instrument in question is unprovided with means for correct orientation of the solar image, the amateur using an altazimuth mount would do well to make his observations about noon, when orientation becomes easy, so that, due attention being paid to the monthly ephemeris for the inclination of the Sun's axis, no very serious difficulty need be experienced in locating within moderate limits of error any individual prominence seen on the solar limb.

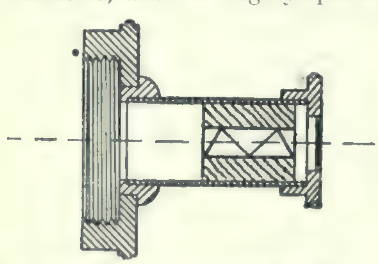


By courtesy of] [*Messrs. Adam Hilger, Ltd.*

ZÖLLNER "OCULAR" STAR-SPECTROSCOPE.

Actual size.

It must be admitted that the manipulative dexterity which the employment of an altazimuth mounting requires in order to keep the solar limb exactly on the slit, is certainly of a far more delicate nature than that necessary for stellar work with a Zöllner spectroscope. But it is easily acquired with practice, and no amateur can ever forget the thrill of pleasure he experiences on picking up his first prominence. The exquisitely delicate outline of these flame-like images, their evanescent character, and the highly-specialised means necessary to render them visible, all conspire to make this department of observational work perhaps the most attractive of all. At the same time, the earnest amateur, as soon as he is able, will lose no opportunity of increasing his aperture to at least four inches, and mounting it on a clock-driven equatorial. He should also endeavour to raise the power of his spectroscope from the simple apparatus described by substituting for his grating a prism-train, if possible after the Evershed pattern, thus augmenting his available dispersion between the A and H lines to something like 60°. Furthermore, for convenience of observation, the slit of his spectroscope should be set eccentric by an amount equal to the semi-diameter of the Sun's image, so that on rotating the instrument the slit passes tangentially



By courtesy of] [*Messrs. Adam Hilger, Ltd.*

ZÖLLNER "OCULAR" STAR-SPECTROSCOPE.

This is made to fit over an ordinary astronomical eyepiece like a sun-cap.

round the limb of the sun, while the spectroscope itself should be furnished with a graduated circle enabling the observer to read off the exact position of the prominences seen on the limb. With his "tele-spectroscope" thus reinforced, the amateur will find himself very efficiently equipped for the successful study of the chromosphere and prominences, and may even venture an attack on the interesting problem of spot-spectra.

It has been truly said that the spectrum is the most profoundly inspired utterance of the celestial bodies that has yet descended to us, and since it is generally agreed that a proper attack on the problem of stellar evolution must begin with the study of the Sun—our nearest star—it is surely a fortunate circumstance that the amateur finds such promising opportunities for individual work in the fruitful and fascinating field of Solar Spectroscopy.

III.

CELESTIAL PHOTOGRAPHY.

By F. W. Longbottom, F.R.A.S.

The debt which Astronomy, the oldest of the sciences, owes to her young sister Photography, is abundantly evident on almost every page of "Splendour of the Heavens," and suggests, amongst many other things, a most pertinent question:

"Is not the well-nigh human machinery which carries the sensitive plate, in the great observatories of the world, slowly eliminating the astronomer from his sphere of work?" The answer comes very readily when it is remembered that the most perfect time-keeper known to the scientist is the steady rotation of our Mother Earth.

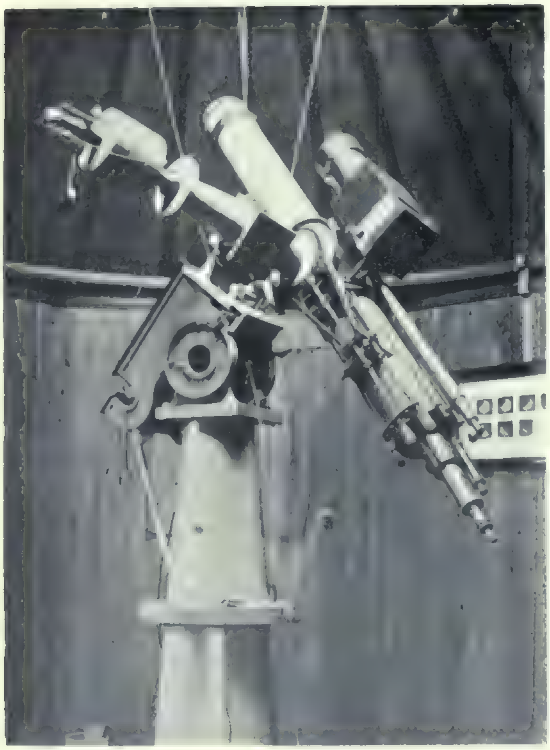
This rotation swiftly sweeps the camera-man and his apparatus past the object he desires to photograph (unless his "sitter" is situated near the celestial poles), and a second clock is usually needed to counteract this movement. Now, all man-made clocks have their individual eccentricity, so the observer can never sleep at his post, but must keep faithful watch lest these opposing clocks are not in agreement.

Then, refraction, both accidental and normal, has to be noted and corrected.

Even with brilliant objects, where the exposure may be cut down to a fraction of a second, that rare instant has to be selected when the atmosphere is tranquil, and definition at its best.

The "man at the small end of the telescope" will ever remain the one indispensable factor. Unhappily, there are far too few of these alert and determined men, and this is the opportunity for the earnest student—professional or amateur. Presupposing that the reader of our pages has gained both the desire to help and some basic knowledge of the conditions involved, a few notes may be helpful. Let it be said at once, that any telescope, and any camera and lens, may be turned to useful account in some branch or other of Celestial Photography. A telescope is only a long camera, and *vice versa*, a camera and lens form a sort of telescope. Either may be used with an eyepiece or a sensitive plate, and sometimes both items are used on the same instrument. Except for "snap-shots," some kind of hand- or clock-driven equatorial stand is necessary; but the ingenious beginner need not find this costly if he makes part of it himself. Refracting telescopes usually work at F.12 to F.15. Sometimes they are corrected for photography, otherwise the best "actinic" focus must be found by experiment.

In reflecting telescopes all foci coincide, and angular apertures as high as F.5, or more, are possible. If a telescope is used as a camera, a second (smaller) one with cross-wires in the focus of the eyepiece is attached, as a pointer, or "guide," to ensure the object being photographed keeping its place on the plate. With a camera strapped to the body of the telescope, the latter is used for such guidance. Portrait-lenses—the bigger the better—with a working aperture of F.3 to F.8, are admirable for stars, nebulae or comets, and at times of total solar eclipse, for photographing the long, faint, "coronal streamers." For these purposes, only the fastest plates are desirable. Those who can command an "anastigmatic" lens, of about twenty inches focus, and F.4·5, are to be envied, as much very valuable work is within their reach. But let not the man with humbler equipment



CAMERA WITH PORTRAIT-LENS,
attached to an Equatorial Telescope, as used by Mr. Mark L. Larman.

despair. Let him rather look at the splendid results obtained by Barnard and others, with cheap "lantern" lenses!

For solar, lunar, and planetary photography, a telescope is most suitable, as the longer focus gives the necessary increase of scale. An equatorial mount is not always needed for brilliant objects, as good images may be secured before the movement due to the rotation of the Earth can blur them.

There must be some means of pointing the instrument aright, and for this purpose a simple form of stand (called an "Alt-azimuth") will suffice. Here, slower, finer-grained plates are advisable, as subsequent enlargement is usual.

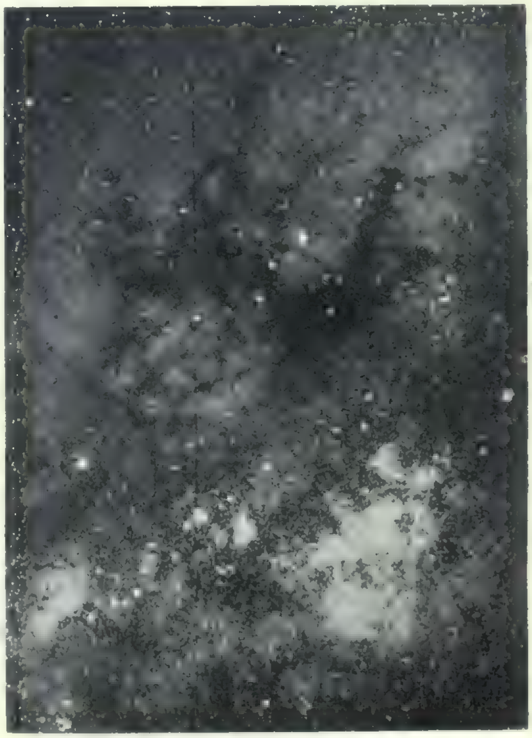
Concerning the selection of the class of work most needing to be done, much might be written; but all turns on the instruments available.

The Sun offers a fine field for continuous study, as changes are constantly taking place on its surface. A telescope of three or four inches aperture would yield good results. A rapid shutter is needed.

The Moon is easily photographed with almost any lens; but, here, the large-scale reflectors hold the cards, and beyond taking a pleasing picture not much can be achieved. This is even truer as regards the planets, as only a highly-magnified image can reveal the finer detail. Charting the whole face of the sky is a large order, but it could be undertaken if a few workers, armed with portrait or other lenses, joined in the task, and if completed periodically, and the plates carefully compared, might lead to the discovery of new or variable stars. A good map of the Milky Way could be made by similar co-operation, and would have a distinct value.

When a comet appears, it should be photographed at frequent intervals, as changes are sudden and remarkable, and the full life-history of a comet has yet to be recorded. Comets have sometimes been found on plates taken for other purposes, so all plates should be closely examined. Comets having a movement of their own, must be "followed" throughout the exposure.

For registering the flight, etc., of meteors, any lens will do, and the camera may be simply pointed



REGION OF THE GREAT STAR-CLOUD IN SAGITTARIUS.
Photographed by Mr. Gale, Junior, with a Goerz "Celor" lens, of 9-in. focus, and F.5. Exposure two hours. Imperial "Eclipse" plate—H. & D. 650.

towards the region selected (*see* page 443), or may be moved with the star-sphere, on the clock-driven equatorial. Much remains to be learnt about meteors, and the photographer must be enlisted to aid in the research.

The Aurora opens up a comparatively unworked possibility for the application of simple apparatus.

Plates, developers, printing papers, transparency making, etc., leave much to the choice of the worker. Most of the methods of manipulation yield good results, but vital matters are the use of freshly-backed plates and the avoidance of all intensifiers.

Photographing the heavens is a lonely cult ; but its devotees form a kindly fraternity, and are ever ready to advise or help the newcomer to their ranks. Then, the British Astronomical Association welcomes students of every branch of astronomy, and through its officers and the directors of its various sections offers friendship and instruction to all.

Finally—The good of it all ? Well, there is the joy of making a record of one's work, which suitable printing methods will render permanent for subsequent study, and the ever-present possibility of adding to the stock of our knowledge of the Universe, coupled with the delight that comes of all creative endeavour.

PART V.

A GLOSSARY OF ASTRONOMICAL TERMS.

Aberration. A term generally applied to the real or apparent deviation of the course of a ray of light. It is used in two senses : (1) The apparent displacement of a star resulting from the combined effects of the velocity of light and the speed of the Earth's orbital motion ; (2) The defects of an uncorrected lens in (*a*) failing to bring light of all colours to the same focus (***chromatic aberration***), (*b*) bringing the rays from its edge to a shorter focus than those passing through its central parts (***spherical aberration***).

Acceleration (*Secular*). A peculiarity affecting the mean motion of the Moon in its orbit round the Earth. Deduced mainly from the study of ancient eclipse records. It is due in part to changes in the eccentricity of the Earth's orbit, but is to some extent apparent only, being a reflex effect of a retardation of the axial rotation of the Earth.

Achromatic. A term applied to an object glass, eyepiece, or other optical system in which the defects of chromatic aberration (see above) have been partly or completely eliminated.

Acronycal. A star or other heavenly body is said to rise acronycally when it is first observable in the east at the shortest possible interval after sunset. It sets acronycally when last observable in the west just before sunrise. In either case the body will be near, but not actually at opposition to the Sun.

Albedo. Literally the degree of whiteness of a body ; more exactly the proportion of sunlight reflected by its surface as compared with the total amount it receives from the Sun. An albedo of 1·0 would imply perfect reflectivity, one of ·75 a 75 per cent. reflection, and so on.

Almucantar. A "small-circle" of the celestial sphere that is parallel with the horizon ; *i.e.*, a parallel of altitude. The term is also applied to a telescope so mounted that, in its rotation about a vertical axis, it sweeps out curves of this kind on the sky. Such an instrument is used chiefly for the exact determination of the position of the observer's zenith in its relation to the star-sphere, and hence his latitude.

Altitude. The apparent angular elevation of a body above the true horizon, usually expressed in degrees, minutes, and seconds of arc. The altitude of the zenith is 90°. To obtain the true altitude a correction must be applied for the effect of refraction (which see).

Annular. Literally "ring-shaped." Applied to (*a*) a solar eclipse in which the Moon passes centrally, or nearly centrally, across the Sun's disc, but has at the time an apparently smaller diameter, so as to leave uncovered a ring of light from the solar limb ; and (*b*) a nebula of the "planetary" class in which the appearance of a ring is produced by the relative faintness of the central portions.

Anomaly. The angle at the Sun between the place of a planet or comet and the perihelion point of its orbit. This is the "true" anomaly. The "mean" anomaly is the angle between the perihelion point and the "mean place," which is the position that would be occupied by the body if it revolved in a circular orbit with uniform velocity. The anomalistic year is the interval elapsing between two successive perihelion passages of the Earth. The anomalistic month is similarly reckoned from perigee to perigee. (*See* Chapter XXII.)

Ant-apex. The point in the sky 180° from that towards which the Sun (with the whole Solar System) is moving.

Ansa. Literally, "a handle." That part of Saturn's ring which is seen projected against the background of the sky on either side of the planet when the system is viewed other than edgewise. The term was first applied in the early days of the telescope, before the true nature of the ring was understood.

Apastron. The point in the real orbit of a binary star at which the smaller component is at its greatest distance from the primary. This point seldom corresponds with that occupied by the smaller star when at its greatest *apparent* distance, but may be found by drawing a straight line from the primary through the centre of the apparent ellipse, and producing it to cut the latter. The point of intersection marks the position of apastron.

Apex. The point in the heavens towards which the Sun is moving. Many determinations of its position have been made. That at present adopted will be found among the "Astronomical Constants."

Aphelion. The point in the orbit of a planet or comet which is most remote from the Sun. This point lies at the extremity of the major axis of the ellipse, nearest to the "empty focus" of the latter; the Sun being, of course, at the other focus.

Apogee. The point in the Moon's orbit which is most distant from the Earth. Also occasionally applied to the position of the Sun when at its greatest distance from us in its apparent orbit, taking the Earth as central. Heliocentrically speaking, the Earth is, of course, at aphelion at the same time.

Apparent Time. The time determined by direct observation of the Sun itself (that is, the "true" Sun). Owing to the varying velocity of the Earth's orbital revolution and the obliquity of the Ecliptic, the Sun crosses the meridian at varying intervals throughout the year, so that this system of time measurement is not suited to modern requirements. (See *Mean Time* and *Equation of Time.*) Apparent time is the time given by a sundial.

Apparition. The period during which a planet, comet or other celestial object is favourably placed for observation. This period lasts, for most objects, from shortly after till shortly before conjunction with the Sun. Circumpolar objects are in "perpetual apparition."

Appulse. An apparently close approach of two celestial objects.

Apsis. A term applied to each of the two points of an orbit which are respectively nearest and farthest from the centre of motion. The "line of apsides" joins these two points (more commonly referred to as aphelion and perihelion, or apogee and perigee, etc.) and forms the major axis of the ellipse.

Areography. The study of the surface of the planet Mars. From the Greek *Ares* (= Mars).

Azimuth. The angular distance of an object measured along the horizon from the north or south points. For objects in the sky it may be defined as the angle between the meridian and the great circle which passes through both zenith and object. The motion of an instrument about a vertical axis is spoken of as motion in azimuth.

Binary. A double star in which the components are physically connected in a gravitational sense, revolving round their common centre of gravity. Stars which appear close together, though actually at greatly different distances from us, are said to form "optical" doubles. The great majority of close pairs are, however, truly binary in character, though large numbers have not been observed long enough to reveal any relative motion.

"Bode's" Law. An empirical law connecting the distances of the planets from the Sun. First propounded by Titius. The law states that by adding 4 to each number in the series 0, 3, 6, 12, 24,

etc., we obtain a new series which represents approximately the relative diameters or radii of the planetary orbits, that of the Earth being 10. The law holds good in a general way for nearly all the planets, but breaks down badly in the case of Neptune.

Bolide. A term often applied to a " fire-ball " or large meteor.

Bolometer. A sensitive electrical thermometer, capable of registering minute differences of temperature. It is used, in conjunction with a large telescope, for detecting and measuring directly the heat radiated by stars and planets. It can also be applied to the study of energy-distribution in stellar spectra.

Chromosphere (*i.e.*, " coloured sphere "). The name given to that part of the Sun's atmosphere lying immediately above the metallic vapours which form the " reversing layer." It is composed chiefly of hydrogen, which shines with a rosy light, and from it the prominences rise. It cannot be seen in the absence of a total eclipse, except with a spectroscope.

Chronograph. An instrument for recording on a revolving drum or similar device minute intervals of time. It was first introduced and is still principally used for the electrical recording of transit observations.

Chronometer. Strictly speaking, any instrument used for the measurement of time, but generally applied only to very accurate portable time-pieces, such as are carried by ships at sea. These are all descended from and similar in principle to Harrison's original chronometer, illustrated on page 705. The works of a typical modern chronometer, which is really a large watch, are shown on page 706.

Circumpolar. A term applied at any place of observation to those stars which never set. The polar distance of such stars must, therefore, be less than the latitude of the place. It follows that, at the terrestrial poles, all the visible stars, down to the celestial equator, are circumpolar. At the terrestrial equator, on the other hand, there are no circumpolar stars.

Co-Latitude. The latitude of a place subtracted from 90°. It is the same as the meridian altitude of the celestial equator at the place of observation, or the zenith-distance of the celestial pole.

Collimation. The setting at right angles to one another of the optical and mechanical axes of an astronomical instrument. The " line of collimation " in a transit instrument is the line joining the optical centre of the object glass with the intersection of the two middle wires at the focus.

A *collimator* is a small telescope placed in line with a larger one to help in adjusting the collimation of the latter. The term is also used with reference to the lens which makes parallel the rays diverging from a spectroscope slit.

Colures. The four principal meridians of the celestial sphere, all of which pass from pole to pole, one passing through each equinoctial and one through each solstitial point. They mark the circles of 0*h.*, 6*h.*, 12*h.* and 18*h.* of Right Ascension.

Comes. (Com'-eez.) A term often applied to the smaller component (or " companion ") of a double star.

Conjunction. The nearest apparent approach of two celestial bodies, which seem to pass each other in their course. They are commonly considered as in conjunction when they have the same longitude, though " conjunction in R.A. " is also often referred to. In the case of the inferior planets, Mercury and Venus, two kinds of conjunction with the Sun are recognised. When they pass the Sun on the near side of their orbit they are said to be in inferior conjunction ; when on the far side, in superior conjunction.

Constant. A quantity, used in astronomical and mathematical calculations, which has always the same value ; *e.g.*, the velocity of light, the solar parallax, the constant of aberration, etc.

Culmination. The passage of a heavenly body over the meridian of a place. This passage may be considered as occurring twice in a day, once above the pole, and again, twelve hours later, below it. The former is called the " upper," the latter the " lower " culmination. The upper culmination of the Sun occurs at noon, the lower at midnight.

Cusps. The point of the " horns " of the Crescent Moon, or of Venus and Mercury when seen in a similar phase.

Declination. The angular distance of a heavenly body north or south of the celestial equator. It is measured on a great circle passing through the body and the celestial pole. When the body is north of the equator, the declination is usually designated +, and when south of the equator, −. Declination in the heavens corresponds exactly with latitude on the Earth.

Density. The relation existing between the weights of similar volumes of matter. In the case of the densities of terrestrial substances, these are expressed in terms of the weight of an equal volume of water. The density of a planet is usually given in terms of the density of the Earth as a whole.

Dichotomy. A cutting in two. A term applied to the aspect of a planet when in the half-illuminated phase, as the Moon at her first and last quarters, and Mercury and Venus at their time of elongation.

Durchmusterung. A catalogue or survey. That compiled by Argelander and his assistants, and known as the Bonner Durchmusterung, contains the positions of over 324,000 stars for 1855. This great catalogue is generally referred to as the "B.D." The letters C.P.D. denote the Cape Photographic Durchmusterung, compiled under the direction of Gill at the Cape, and recording stars in the southern hemisphere down to about the same limits as those adopted by Argelander, whose catalogue stops short at Declination −2°. (It was, however, later extended by Schönfeld to Declination −24°.)

Eccentricity. A measure of the degree of ellipticity of a planetary, cometary or stellar orbit. It is expressed as a decimal fraction of the semi-axis major of the ellipse, the quantity considered being the distance of either focus from the centre. Thus, where the focus is one-fifth of the semi-axis major from the centre, the eccentricity is said to be 0·2. The eccentricity of a circle is, of course, zero. That of the Earth's orbit is about 0·017, or nearly $\frac{1}{60}$.

Ecliptic. The great circle of the celestial sphere along which the Sun apparently travels during the year. It is a reflex effect of the motion of the Earth in its orbit, and is thus identical with the apparent path of the Earth as it would be seen from the Sun.

Egress. The end of a transit of Mercury or Venus, when the planet passes off the Sun's disc, or of that of a satellite as it leaves the disc of its primary. This phenomenon consists of two phases. When the object in transit first touches the limb with the outer portion of its disc, "internal contact" is said to take place. When the whole object is just outside the limb the phase is that of "external contact." The same terms are used with reference to the end of a total or annular eclipse of the Sun.

Elements. In general, the data for predicting an astronomical phenomenon. Especially, the quantities which determine the motion of a planetary body. The independent elements of a planet are six in number, namely: the mean distance, the eccentricity, the longitude of the ascending node, the inclination of the orbit to the ecliptic, the longitude of perihelion, and the mean longitude at some given epoch.

Elongation. The apparent angular distance of a body from its centre of motion in either direction, as of Mercury and Venus from the Sun, or of a satellite from its primary. The expression "at elongation" is generally taken as meaning the maximum angular distance during the revolution under observation.

Emersion. The reappearance of the Moon or a planetary satellite after being eclipsed in the shadow of its primary. In the case of an occultation, the term "reappearance" is more often used.

Ephemeris. A table giving the apparent position of a heavenly body from day to day, so that observers may know where to look for it. Applied also to an astronomical almanac giving a collection of such tables; thus the publication corresponding in the United States to the British Nautical Almanac is known as "The American Ephemeris."

Epoch. A date of reference used in astronomical calculations. The term is employed generally in two senses. (1) The date of a star-chart or catalogue at which the co-ordinates given will be strictly correct, having regard to the effects of precession. (2) An arbitrary starting-point for calculations, such as the date on which a planet occupies a certain heliocentric longitude, or on which a variable star is at its maximum phase.

Equation of Time. The number of minutes or seconds which it is necessary to add to or subtract from Apparent Time to obtain Mean, or uniform, Time, as indicated by a good clock. (*See* Chapter XIX.)

Equinox. Either of the two points at which the Sun, in its apparent annual course among the stars, crosses the celestial equator. So called because, when the Sun is at these points, the days and nights are of equal length (twelve hours each) throughout the world. In the northern hemisphere the Vernal, or Spring Equinox, occurs on or about March 21, and the Autumnal Equinox on September 23. In the southern hemisphere the names must be interchanged, though the dates, of course, remain the same.

Evection. An inequality in virtue of which the Moon oscillates about $1\frac{1}{4}°$ on each side of her mean position in a period of thirty-one days, nineteen hours. It is due to the action of the disturbing force of the Sun, which produces periodical changes in the eccentricity of the Moon's orbit, depending on the position of the line of apsides.

First Point of Aries. The point on the celestial equator reached by the Sun at the Vernal Equinox. It was formerly in the constellation Aries, whence its name, but the effect of precession has been to make it retrograde into the next zodiacal constellation, Pisces. In course of time it will pass right round the Zodiac, reaching its present position once more in about 26,000 years.

Flash Spectrum. The emission, or bright-line spectrum, visible for a few seconds at the limb of the Sun when the Moon has just completely covered the bright photosphere in a solar eclipse. It is due to the shallow low-lying layer of metallic gases which produce the absorption lines in the normal solar spectrum, each dark line becoming bright for the short space during which the layer is uncovered.

Geocentric. (1) Referred to the Earth as centre (*e.g.*, the Ptolemaic idea of the Solar System). (2) Referred to the centre of the Earth as a view-point, as in the case of certain predicted apparent positions of heavenly bodies.

Gravitation. The tendency of all bodies in the Universe to attract one another with a force proportional to their combined mass and inversely proportional to the square of their distance apart.

Gibbous. An adjective applied to the apparent shape of a planet or the Moon when more than half but less than the whole illuminated portion is visible (as between first-quarter and full moon). Mercury and Venus exhibit this, and all other aspects of the Moon, but the gibbosity of the exterior planets, with the exception of Mars, is never marked, and none such can appear less than half illuminated.

Great Circle. A circle whose plane passes through the centre of a sphere, dividing the latter into two equal portions, or hemispheres. The ecliptic, the celestial and terrestrial equators, and all meridians of Right Ascension or longitude are examples of Great Circles. A "small circle" is one which divides the sphere unequally, its plane not passing through the centre. Examples are the parallels of declination and terrestrial latitude, excluding the equator in each case.

Heliacal. Applied to the risings and settings of stars when these phenomena are observed respectively as early or as late as is possible with unaided vision. Such observations were used by early astronomers for the purpose of determining the position of the Sun in the Zodiac, and less accurately for marking the progress of the seasons.

Heliocentric. (1) Referred to the Sun as a centre (*e.g.*, the Copernican System). (2) Referred to the centre of the Sun as a view-point. In determining the future places of planets, comets, etc., their heliocentric positions are first of all calculated, and then, by taking the Earth's motion and position into account, their geocentric positions. A further correction for parallax must be made in order to arrive at their *apparent* positions as viewed at any particular place and time.

Horizon. (1) Celestial or sensible horizon. The tangent plane to the surface of the Earth at the place of observation, produced to meet the star sphere. (2) Apparent horizon. The same, as actually affected by refraction and by the height of the observer above the surface. (3) True horizon. A plane through the Earth's centre parallel to the celestial horizon. Note that (1) is a great circle, and also (3) in the case of distances that are almost infinitely great, as with the stars; but (2) is generally a small circle.

Immersion. The disappearance of a celestial body due to its passing into the shadow thrown by another. Familiar examples are eclipses of the Moon and of Jupiter's satellites.

Inequality. (1) Moon's parallactic; an inequality in the Moon's motion due to the varying amount of the Sun's disturbing force at new and full Moon. It tends to accelerate the time of first quarter and to retard that of last quarter. (2) Of Jupiter and Saturn; an inequality in the orbital motion of these large planets due to their mutual attraction, enhanced in its effect by the close commensurability of the two periods. Two periods of Saturn are nearly equal to five of Jupiter.

Ingress. The beginning of a transit of Mercury or Venus, or of that of a satellite as it enters on the disc of its primary. The opposite of egress (which see). Two phases are exhibited, external and internal contact. Where the predicted time of each of these phases is not given, the term is generally taken to denote the phase intermediate between the two, *i.e.*, the moment when the centre of the smaller body is on the limb of the larger. The same applies to predictions of egress.

Latitude (*Celestial*). The angular distance of a heavenly body from the ecliptic, measured on a great circle at right angles to it. In the early days of instrumental astronomy the positions of all celestial objects were commonly referred to the ecliptic rather than to the equator, but at the present time this is no longer the practice, except for members of the solar system.

Latus Rectum. The chord drawn through the focus of a conic section at right angles to the major axis.

Libration. The apparent rotational oscillation of the Moon's disc, whereby small portions of the normally invisible hemisphere are alternately brought into view. Libration occurs in longitude (E.—W.) and latitude (N.—S.). The former is due to the irregular velocity of the Moon in her elliptical orbit, combined with her uniform rotational velocity; the latter to the fact that her axis of rotation is not exactly perpendicular to the plane of her orbit.

Light Year. The distance travelled by light in one year, which is 62,900 times the distance of the Earth from the Sun, or nearly six billion miles. It is a unit commonly employed in statements of star-distances, which are all so vast that the retention of the mile as unit would involve the use of figures that would be unwieldy and nearly meaningless. The light-year is now being replaced, at least for the greater distances, by a still larger unit, the "parsec" (which see).

Limb. The apparent edge of the disc of any celestial body, as seen in circular projection from the Earth or any other specified view-point.

Limits (*Ecliptic*). The angular distance along the ecliptic, from the Moon's node, within which an eclipse is possible. For Solar eclipses the Moon must be within 16° 58′ of the node. For Lunar eclipses the Sun must be within 11° 21′ of the Moon's node to insure contact with the *umbra* of the Earth's shadow.

Local Time. The Mean Time at any particular place. It can be found by applying the "Equation of Time" correction* to a noon observation of the "True" or "Apparent" Sun, or by correcting the known Mean Time of some standard meridian (such as that of Greenwich) by an amount corresponding to the difference of longitude of the two places. It can also be found, less directly, by determining the local Sidereal Time from the transit of a star, and converting to Mean Time by the use of standard tables.

Longitude. (1) Terrestrial. The angular distance of a place on the Earth's surface east or west of some fixed meridian, such as that of Greenwich. Reckoned either in hours, minutes and seconds of time, or in degrees, minutes and seconds of arc, as referred to the great circle of the Equator. (2) Celestial. The angular distance of a celestial body from the First Point of Aries (which see), reckoned in degrees, etc., of arc. Its use as a co-ordinate is now confined to the planetary system, as explained under *Latitude*.

Luminosity. The *real*, or actual, output of light of a star or similar body referred to some standard, as opposed to its *apparent* brightness as seen from the Earth. (See *Magnitude*.)

*As the amount of this correction is constantly changing, and is only given for Greenwich Mean Noon, a rough knowledge of the longitude of the place is necessary for estimating its amount at any given local time.

Lunation. The period from new Moon to new Moon, or that elapsing between any two similar phases. It is the same as the Synodic month, its length being 29*d*. 12*h*. 44*m*. 2·7*s*.

Magnitude. (1) Apparent. The apparent brightness of a star or other heavenly body as compared with some adopted conventional standard, such as the Pole Star. Stellar magnitudes are divided into classes, whose mutual relations are such that any star is 2·512 times as bright as one that is a magnitude fainter. Apparent magnitudes are classed as Visual, Photographic, Photo-electric, or Photo-visual, according to the methods used in their determination (*see* Chapter XV). (2) Absolute. The apparent magnitude which any star would have if situated at one particular distance, arbitrarily fixed at ten parsecs, or 32·6 light-years. All stars being referred to this same distance, it follows that determinations of their absolute magnitudes give a measure of their true relative luminosities. Of course, the distance of a star must first be known before its absolute magnitude can be inferred.

Major Axis. The straight line passing through the foci of an ellipse and marking its greatest diameter.

Mass. The quantity of matter contained in a body. It is measured in terms of weight, but differs from the latter in that it is independent of the force of gravity at the point which it occupies. The masses of the heavenly bodies are measured by the attraction they exert on other bodies, and are reckoned in terms of that of the Sun.

Mean Time. Uniformly flowing time, as indicated by a good clock or similar mechanism. It is regulated by the motion of the " Mean Sun," an imaginary body moving at uniform angular speed round the celestial equator. (*See* Chapter XIX.)

Meridian. (1) Celestial. The great circle of the celestial sphere which passes through the poles and the zenith of the place of observation. This is *the* meridian of a given place, but all great circles passing through the celestial poles are called meridians of Right Ascension. (2) Terrestrial. Any great circle passing through the poles of the Earth. The observer's particular meridian passes also through his position on the surface. The " Prime " meridian is that adopted by any country or countries as a zero for the determination of longitude. That of Greenwich is now in almost universal use.

Metonic Cycle. A lunar cycle discovered by Meton and Euctemon in B.C. 432. They found that, after a period of nineteen years, new and full Moons recurred on the same days of the year. The Metonic Cycle is 235 synodic months, or 6939·69 days in length ; almost exactly nineteen tropical years.

Nadir. The point on the celestial sphere vertically below an observer at any point on the Earth's surface. It is determined by the direction of the resultant of gravitation at the point, and is indicated by a plumb line, or a line normal to the plane of a liquid surface, such as that of mercury. It corresponds to the zenith of a place at the antipodes.

Node. The points in which the orbit of a planet or comet cuts the plane of the ecliptic. The node at which the body is rising from the southern to the northern side of the ecliptic is called the *ascending node*, and that at which it is passing from the northern to the southern side, the *descending node.* The line joining these two points is called the *line of nodes*, and is evidently the line of intersection of the two planes.

Nutation. A small variation in the regular precessional revolution of the celestial poles round the pole of the ecliptic, due to the action of the Moon. Its period is the same as that of a sidereal revolution of the Moon's nodes, or about 18 years 220 days. Discovered by Bradley.

Obliquity of Ecliptic. The angle between the plane of the equator and that of the ecliptic, which is equal to half the difference of the meridian altitude of the Sun at mid-summer and mid-winter. Its amount is subject to a cyclical change between the limits $21° 59' \pm$ and $24° 36' \pm$. The value at present is about 23° 27′ and it is diminishing at the rate of about 47″ per century. Its principal effect is the production of the seasons.

Occultation. The disappearance of a distant celestial body through interposition of a nearer one of greater angular diameter. The term is most commonly applied to the hiding of a star or planet

by the Moon, or of a satellite or star by a planet. A total solar eclipse is, strictly speaking, an occultation of the Sun, though not usually so described.

Opposition. The relation of two bodies in opposite directions. A planet or comet is said to be in opposition when its geocentric longitude differs by 180° from that of the Sun, or in other words, when both the Earth and the body are in the *same* heliocentric longitude, the Earth being the nearer to the Sun. At such a time the body rises at sunset, sets at sunrise, and is, in general, most favourably placed for observation, as it crosses the meridian at midnight. It follows from the definition given above that only a body exterior to the Earth's orbit can be in opposition.

Parallax. In general, the apparent angular change in the position of an object due to real change in the observer's position. It follows from this that the angle thus measured will be the same as that subtended at the distant object by the projection of the line between the two stations of observation. A star's parallax is expressed as the angle subtended by the radius of the Earth's orbit as seen from it. In the case of a member of the solar system the parallax is the angular subtense of the Earth's equatorial radius as seen from the body. It is clearly the same as the apparent displacement of the object as it passes from the meridian to the horizon of a place on the equator, and is hence termed the "horizontal" parallax.

Parsec. A unit of celestial measurement lately brought into use. It represents a distance corresponding to a parallax of one second of arc, and is equivalent to 3·26 light-years. No stellar distance yet measured is quite so small as this, the nearest known star being situated at 1·2 parsecs, or 4·1 light-years.

Penumbra. (1) The partial shadow which borders the dark shadow of the Earth in an eclipse of the Moon. At the points of the Moon's surface covered by the penumbra, the Sun is seen partially eclipsed. The shadows of all objects exhibit penumbrae when the source of light is of sensible angular diameter as seen from the body on which the shadow is cast. (2) The lighter shade surrounding the darker portion, or *umbra*, of a sun-spot.

Periastron. The point in the *real* orbit of a binary star at which the components are at their closest. It lies on the same line as the apastron point (which see) and is found in the same way. It seldom corresponds to the position in which the components *appear* at their closest, as viewed from the Earth.

Perigee. The point in the Moon's orbit that is nearest to the Earth. As a result of the eccentricity of the orbit, which is more than three times as great as that of the Earth, the apparent diameter of the Moon varies between about 33′ 30″ and 29′ 21″ in the extreme between perigee and apogee, though the range is not so great as this at every lunation, owing to a periodic variation of eccentricity caused by perturbations. The range of this quantity is from about one-fourteenth to one-twenty-second.

Perihelion. The point in the orbit of a planet or comet at which it is nearest to the Sun. The prefixes apo- and peri- are also used to denote points in the orbits of the satellites of various planets corresponding to aphelion and perihelion, apogee and perigee, etc. (*e.g.*, peri-Jove, peri-Saturnium).

Perturbation. A disturbance or inequality in the regular motion of a heavenly body, produced by some force additional to that which causes the regular motion. The perturbations of the planets are caused by their mutual attractions, and those of comets by the attractions of the planets near which they pass.

Phase. A particular aspect of a celestial body, or stage of some phenomenon, the occurrence of which is subject to progressive or periodic change. Thus we speak of the phases of the Moon and Venus, and also of the successive phases of a lunar eclipse or a transit of Venus. Such stages as Ingress, Egress, Immersion, etc., are examples of the phases of different phenomena.

Photometry. The quantitative measurement of the relative apparent brightness of different celestial objects, effected by instruments designed for the purpose. (*See* Chapter XV.)

Photosphere. The visible surface of the Sun, from which the vast majority of its light proceeds. Its true nature is still unknown, since the continuity of its spectrum defies analysis.

Polarity. A term used to define the character of the magnetic field surrounding a sun-spot. Polarity may be positive or negative, according as the magnetic field corresponds in type with similar fields so-named by convention in terrestrial magnetism.

Position-angle. The angle between the line joining the components of a double star and the meridian of Right Ascension passing through the primary star, *i.e.*, the N.–S. line. The angle is measured from 0° to 360°, starting at the north point of the field and reckoning towards the east, or counter-clockwise. The brighter of the two stars is always taken as the origin and the position-angle of the pair is given by the direction in which the companion lies with regard to it. (*See* diagram on page 517.)

Precession. A slow change in the position of the celestial equator, which causes the equinoctial points to retrograde along the ecliptic. This is due to the pole of the equator revolving round the pole of the ecliptic in a period of about 25,800 years. This motion is caused by the disturbing effect of the attractions of the Sun and Moon on the protuberant matter at the Earth's equator. The precession of the Equinoxes was discovered by Hipparchus.

Prime Vertical. The great circle of the celestial sphere which passes through the zenith, nadir, and the east and west points of the horizon.

Proper Motion. The apparent angular motion (annual or centennial) of an individual star relative to its surroundings as a whole. In most cases it is due to the combined effect of the star's own motion and that of the solar system. To obtain the star's *true* velocity, relative to the visible universe, it is necessary to find also the rate of its motion in the line of sight and, after finding its distance, to reduce its apparent angular motion to a linear value. In both cases, of course, the known velocity and direction of the Sun's motion must be allowed for.

Quadrant. (1) The fourth part of a circle, comprising 90° of the circumference as viewed from the centre. (2) An instrument designed for measuring angles up to 90°. Much used by the earlier astronomers, especially at the epochs immediately preceding and following the invention of the telescope. The mural quadrant was mounted on a section of wall lying in the meridian, and performed the functions of the transit-circle of later days. Such quadrants were divided direct to 90° along their entire arc. Hadley's quadrant, the forerunner of the modern sextant, was only 45° in extent; but, as it worked on the reflecting principle, each ½° corresponded to 1° in the measurement of angles, and was therefore so marked. (*See* pages 768 and 820.)

Quadrature. A term applied to the position of a planet or similar body when its geocentric longitude differs from that of the Sun by 90°. The Moon is in quadrature when at her first and last quarters. The outer planets exhibit their maximum phase, or apparent defect of illumination, when so placed.

Radiant. That point or small area in the heavens from which the members of a meteoric shower appear to diverge. Actually the paths of the meteors are sensibly parallel to one another, their divergence being an effect of perspective.

Radius Vector. The line drawn at any moment from a moving body to the centre round which it moves. In a circular orbit the radius vector is constant in length, being equal to the radius of the circle, but in an elliptic orbit it varies in length with the position of the moving body.

Rate (*Clock*). The amount by which a clock gains or loses in twenty-four hours. If the clock loses the rate is positive (+), and if it gains it is negative (−). The steadiness or uniformity of rate is the true test of the excellence of a clock. Its error (the cumulative effect of its rate) is immaterial, so long as its exact amount is known, though it may cause some inconvenience if allowed to become too great.

Refraction. The bending of a ray of light which takes place when it passes from one transparent medium to another of different density. Familiar astronomical examples are the action of the lenses of a telescope, and that of the atmosphere. In the latter case the effect, apart from minor irregularities and distortions, is to increase the apparent altitude of all celestial objects except those situated in the zenith. The amount of this elevation is at a maximum on the horizon. Atmospheric refraction is influenced to some extent in its amount by the temperature and density of the air which causes it.

Retrograde Motion. (1) The apparent reversal of the ordinary west to east motion of a planet or comet among the stars, due to the Earth's own orbital motion in the same direction. In the case of an exterior planet it occurs only near the time of opposition, at which point it reaches its maximum. (2) Applied to the *real* motion of a satellite or comet when it is opposite in direction to the normal motion for such bodies, which is counter-clockwise as viewed from the north side of the ecliptic.

Reversal. (1) Instrumental. A method of testing the collimation adjustment of a transit instrument by reversing the telescope in its supports, so that the eastern end of the axis shall lie in the western support, and *vice versa*. (2) Photographic. The direct production of a positive instead of a negative image of a bright object on a photographic plate, generally the result of violent over-exposure. (3) Spectroscopic. The occasional or periodic change in the character of the lines in a spectrum, either from bright to dark, or from dark to bright. The Flash Spectrum (which see) is an example of bright reversal, and the stratum of gases causing it is consequently referred to as the "reversing layer."

Right Ascension. The angular distance of a celestial body from the First Point of Aries, measured in an easterly direction along the equator. It is occasionally reckoned in degrees, minutes and seconds of arc, referred to the equator as a great circle, but more commonly in hours, minutes and seconds of sidereal time. It corresponds to terrestrial longitude, the First Point of Aries being the "Greenwich" of the celestial sphere. It is, however, measured continuously in one direction up to twenty-four hours, whereas terrestrial longitude is measured in two directions, up to 180° east and west.

Saros. A lunar cycle discovered by the Chaldaeans. It is eighteen years and eleven and one third days in length (or ten and one third days if there have been five leap years in the interval), and corresponds to the period of revolution of the nodes of the Moon's orbit with reference to the Sun. Hence after this period the solar eclipses will tend to repeat themselves in the same order. During the period of the Saros the number of eclipses is about seventy ; twenty-nine of the Moon and forty-one of the Sun.

Scintillation. The twinkling of stars, due chiefly to the mutual interference of rays suffering refraction in varying directions through inequalities of atmospheric density. On nights when telescopic definition is at its best there is little or no twinkling of the stars. Planets, especially those of large apparent diameter, do not exhibit the phenomenon of scintillation unless very low in the sky, or when the atmosphere is exceptionally disturbed. Mercury, having a small disc, and appearing always near the horizon, seldom shines with a perfectly steady light.

Secular. Applied to changes or processes which are either indefinitely progressive or take place over immense periods of time (*e.g.*, the secular acceleration of the Moon's mean motion).

Selenography. The study of the physical features of the Moon's surface.

Sidereal Time. Time measured by the rotation of the Earth with regard to the star-sphere as a whole. It varies with the longitude of each place on the Earth, being defined as the hour-angle (west of the meridian) of the First Point of Aries. It is reckoned continuously to twenty-four hours from this point, and it therefore follows that any given star crosses the meridian at the local sidereal time which is equal to its Right Ascension.

Solstices. The points on the Ecliptic which lie at the maximum distance north and south of the celestial equator. The Sun occupies the northern point (the summer solstice of the northern hemisphere) on June 21, and the southern on December 21. At the present time the northern point (always at 6*h*. of R.A.) is among the stars of Gemini near the "feet," and the southern (always at 18*h*. of R.A.) in the constellation Sagittarius. Reference to an almanac will show that, on these days, the Sun enters the *signs* Cancer and Aquarius respectively, but, owing to precession, these signs no longer correspond to the constellations originally associated with them.

Sothic Cycle. The period in which any particular day in the ancient Egyptian year of exactly 365 days would travel completely round the seasons. It was reckoned to commence at the date when Sirius (Sothis) rose heliacally at the Winter Solstice of the northern hemisphere, and was calculated by the Egyptians to be 1,461 years in length. Actually it would be about 1,500 years long.

Spheroid. A solid whose surface would be defined by the rotation of an ellipse round one of its axes. If the rotation is considered as taking place round the minor axis the spheroid is said to be *oblate,* and, if round the major axis, *prolate.* A rotating spherical body tends to assume the figure of an oblate spheroid, the amount of oblateness depending upon the angular speed of rotation. The Earth is a slightly, and Jupiter a considerably, oblate spheroid.

Stationary Points. The points in a planet's orbit at which the body appears stationary (as regards its motion in longitude) among the stars as seen from the Earth. Commonly, two stationary positions are reached during a comparatively short period, enclosing between them the arc of retrogression, which is greatest in apparent length for a near planet. For an outer planet these points will obviously be reached some little time before and after opposition respectively.

Synodic. A term applied to the movements or periods of planetary bodies relative to the Sun. The synodic movement of a planet is the amount by which its motion exceeds or falls short of that of the Earth round the Sun, while its synodic period is the time which elapses between two successive returns to inferior or superior conjunction, or to opposition. The synodic month is the period from New Moon to New Moon, and is the same as a " lunation."

Syzygy. The position of the Moon when at either the New or Full phase, *i.e.*, when at conjunction or opposition.

Terminator. The line which divides the dark from the illuminated portion of the disc of a planet or of the Moon. In the case of a body rotating with regard to the Sun it marks the region of sunrise or sunset, as the case may be. At new and full Moon, or for a planet at similar phases, the terminator coincides with the limb, or apparent margin of the disc.

Transit. (1) The passage of a celestial body across some fixed geometrical line, such as the meridian or the prime vertical. (2) The passage of a body between the eye of an observer and an apparently larger object beyond, so that the nearer object appears projected on the face of the more distant one. Applied especially to passages of Mercury and Venus across the disc of the Sun, or of the satellites of Jupiter or Saturn across the disc of the planet.

Trepidation. A supposed oscillation of the ecliptic, having a period of about 7,000 years, imagined by the Arabian astronomers to account for the discordances in the determination of the period of precession. In consequence of this motion, the equinox was supposed to oscillate backward and forward through a space of about twenty degrees. It is now known that " trepidation " has no foundation in fact.

Tropics. The two parallels, or " small circles," on the Earth's surface which have each a latitude (north and south respectively) equal to the obliquity of the ecliptic, or about 23° 27′. The northern parallel is called the Tropic of Cancer, since the Sun is overhead at that latitude when it reaches that *sign.* The southern, for a like reason, is called the Tropic of Capricorn. In popular parlance, the term " tropics " is generally, though incorrectly, applied to the region lying between these two parallels.

Tropical Year. The time which elapses between two successive passages of the Sun through the Vernal Equinox, or " First Point of Aries." The length of the Tropical Year is 365*d.* 5*h.* 48*m.* 45·51*s.*, or approximately 365¼ days.

Twilight. The refracted sunlight, visible after the Sun has set or before it rises. It is always reckoned to begin and end when the Sun is 18° below the horizon. In all places in the northern hemisphere having a latitude greater than 48½°, twilight lasts all night on June 21. The same holds for places south of latitude 48½° south on December 21. In London twilight lasts all night from May 23 to July 20.

Umbra. (1) The dark central portion of the shadow of the Earth or any other opaque body. Within this, the true shadow, a spectator would see a total eclipse of the Sun, but from the penumbra a partial one. In the case of a lunar eclipse the portions of the Moon within the umbra appear ruddy or copper-coloured owing to the refraction and selective absorption of the Sun's light by the Earth's atmosphere. (2) The darkest, generally the central, portion of a sun-spot.

Variation (*Lunar*). An inequality in the motion of the Moon, due to the varying amount of the Sun's disturbing force. This causes a maximum velocity of motion at new and full Moon, and a minimum velocity at the "quarters," or quadratures.

Vertex. The top of the discs of the Sun, Moon or planets, or the point at which a great circle, passing through the zenith and the centre of the disc, intersects the upper limb as seen erect in the sky. Thus the position of the vertex on the disc depends on the azimuth of the object and only corresponds with the north or south point at the moment of meridian passage. In predictions of occultations the points on the Moon's limb at which the stars are to disappear or reappear are reckoned in angle from the vertex as well as from the north point.

Zenith. The point of the celestial sphere which is directly overhead, and the direction from which a plumb line would fall. Its apparent place in the heavens is determined entirely by the position of the observer on the Earth, and the time of the observation. For a fixed observer the Declination of the Zenith remains constant (neglecting the minute periodic change in his latitude), and is equivalent to his latitude. Its Right Ascension is, of course, constantly changing with the rotation of the Earth.

Zodiac. A belt of the sky extending along the ecliptic, within which the Sun, Moon and larger planets always remain. It is generally considered as extending about 8° or 9° on either side of the ecliptic, being thus 16° or 18° in breadth. The twelve "signs" into which it was divided by the ancient astronomers no longer correspond to their appropriate constellations, owing to the effect of Precession.

PART VI.

A SHORT SURVEY OF THE HISTORY OF ASTRONOMY.

By W. Alfred Parr, F.R.A.S.

At the close of a work like the present, which has marshalled before the reader's eyes the pageantry of the heavens in some of its most marvellous aspects, but in which from the very nature of the book itself no attempt has been made to follow any historical sequence, it seems more than usually imperative that, in order to obtain a proper sense of perspective, a short account should be given of the gradual development of the science which, more than any other, has brought man into touch with the infinite. There is scarcely a subject which loses more than astronomy by any attempt to dissociate it from its history. In no other sphere of knowledge is the gradual unfolding of human genius so palpably shown as in this slow endeavour throughout the centuries to unravel the mysteries of the stars. A brief survey, therefore, of the various steps by which mankind has come into possession of its present vast store of astronomical knowledge can scarcely fail to interest those who have yielded to the fascination of the foregoing pages. At the beginning of the Seventeenth Century Kepler wrote in memorable words: "For it is my opinion that the occasions by which men have acquired a knowledge of celestial phenomena are no less admirable than the discoveries themselves," and few will deny that the history of the oldest and grandest of the Sciences possesses a charm far transcending that of many another record of human activity. It has been truly said of mathematics, upon which the whole science of practical and theoretical astronomy is based, that its history is one of the windows through which the philosophic eye looks into past ages and traces the line of intellectual development. Human progress is intimately associated with scientific thought, and the problems of astronomy, in particular, have ever called the mind's highest energies into requisition.

The history of our science naturally falls into three great departments. Its early beginnings were purely geometrical and were concerned solely with the determination of the positions and relative motions of the heavenly bodies. This was the era of *observational* or *practical* astronomy, which was cultivated by the nations of antiquity and brought to such a relatively high state of perfection by that remarkable people, the Greeks. Indeed, their system dominated the science for fourteen centuries, and has even left its indelible impress on our science of to-day. From the days of Kepler and Newton, however, the idea of a compelling cause for the observed motions began to assert itself, so that the

second era was characterised by the dynamic conception which created that *gravitational* or *theoretical* astronomy which runs parallel with and permeates the older form. To this amalgamation a third kind of astronomy was added with the advent of the telescope. This last division of the celestial science is the *descriptive* or *physical* astronomy which Galileo called into being when he applied the newly invented telescope to the heavens, and which has formed the bulk of the material treated of in the pages of this work. The telescope, the most potent weapon that astronomy has ever possessed, at once widened and deepened the science in a manner that can scarcely ever be equalled. The frontiers of the universe were pushed back, so to speak, at one blow, and ever since the early pioneer observations of Galileo the process has gone on until, with those powerful adjuncts of the telescope—the camera, the spectroscope, and the interferometer—man has been able to fling his outposts farther and farther afield into the realms of immensity.

To chronicle as concisely as possible the salient features of this onward march of the forces of astronomy is the object of the accompanying chart, which offers, as it were, a bird's-eye view of the history of the science. Beginning with the year A.D. 1500, the epoch immediately succeeding the Revival of Science in Europe, and continuing down to the present day, the chart presents in its vertical columns a chronometrical, and in its horizontal columns a contemporary, miniature history of astronomy, which will be found to embrace the chief biographical, theoretical, and instrumental details of any given period. In order to bring the whole scheme within reasonable dimensions, the vertical spaces have been arranged in periods of fifty years, so that the various landmarks in the evolution of modern astronomy appear in close perspective. This method serves to show in a graphic manner how completely each stage in the progress of the science has depended on that which went before, while it also affords a comprehensive mental picture of the development as a whole. A sense of proportion, also, is thus imparted to the conception of history which can rarely be gained from a mere perusal of abstract dates or a study of isolated periods. Moreover, by adopting this system of charting it is possible to enter on a separate study of the contained matter in a specific way, for the descending columns give a compressed history of any particular *subject*, while the horizontal columns treat of any particular *period*, and they may thus be utilised as a kind of index to the appropriate subjects which are so fully described in other portions of this work.

Before, however, entering upon a detailed study of the chart itself, it will be well to take a rapid glance at the leading discoveries which man had succeeded in making throughout the long ages that preceded the time of Copernicus. Thus we begin with

PRIMITIVE ASTRONOMY.

From the earliest times the Heavens had been studied in Egypt, India, and China. The path of the Sun and Moon amongst the stars had been found to follow a zone which for convenience of seasonal recognition was divided into the series of star-groups known as the ZODIAC. The primary divisions of the year and month were determined, the motions of the five planets MERCURY, VENUS, MARS, JUPITER, and SATURN were studied, and the OBLIQUITY OF THE ECLIPTIC was measured by the nations of antiquity, the most systematic astronomical observations being those of

THE CHALDEANS,

who map out the CONSTELLATIONS about 2000 B.C., and who discover that the PHENOMENA OF ECLIPSES repeat themselves in the SAROS PERIOD, or cycle of eighteen years. The next great advance is made by

THE GREEKS.

640 B.C. THALES OF MILETUS holds the Earth to be spherical, and predicts a solar eclipse. (The *Gnomon* is in use, and *Sundials* are constructed.)

580 B.C. PYTHAGORAS, according to his disciple PHILOLAUS (400 B.C.), speculates upon the motion of the Earth, and notices that the planets move in separate orbits.

408 B.C. EUDOXUS OF KNIDUS demonstrates the planetary motions by the aid of geometry, and sets up the hypothesis of CONCENTRIC SPHERES (afterwards elaborated by his pupil KALIPPUS) and thus inaugurates the era of *Scientific Astronomy* as distinct from philosophical speculation.

[*Continued on page* 976.

CHRONOMETRICAL CHART OF THE DEVELOPMENT

PERIOD.	BIOGRAPHICAL.	THEORETICAL.
A.D. 1500 [Time of Henry VIII, Edward VI.]	Copernicus, 1473–1543 (Works in Polisn Prussia). Tycho Brahé, 1546–1601 (Denmark and Bohemia).	The Geocentric System of *Ptolemy*, which (geometrically valid though physically inadmissible) had been dominant for 14 centuries, is brought to renewed prominence by *Peurbach* (d. 1461) and *Regiomontanus* (d. 1476); but the Heliocentric System is definitely revived by *Copernicus* in his "*De Revolutionibus Orbium Celestium*" (1543) which, however, still retains the assumption of uniform circular motion with eccentric and epicycle.
1550 [Mary, Elizabeth.]	Galileo, 1564–1642 (Italy) Kepler, 1571–1630 (Bohemia and Germany) Scheiner, 1575–1650 (Germany)	*Tycho*, by collecting a vast mass of valuable observations, prepares the way for the theories of *Kepler*, who, finally discarding the geometrical makeshifts of the Ancients, adopts the elliptical form of orbit and introduces the Dynamic Conception into Astronomy by his *Three Laws* of the planetary motions. These form the connecting link between the theories of *Copernicus* and the discoveries of *Newton*.
1600 [James I, Charles I, Common-wealth.]	Hevelius, 1611–1688 (Germany) Horrox, 1619–1641 (England) Huyghens, 1629–1695 (Holland) Newton, 1642–1727 (England) Flamsteed, 1646–1719 (England)	*Galileo*, by his telescopic discovery in 1610 of Jupiter's Satellites and the Phases of Venus, firmly establishes the Copernican doctrine, and lays the foundation of Observational Astronomy. *Scheiner*, from the observation of Sunspots, discovered in 1610 by *Fabricius* and *Galileo*, determines the Sun's rotation. *Horrox* predicts on dynamical principles, and is the first to observe (with *Crabtree*) a Transit of Venus in 1639. *Napier* facilitates astronomical calculation by his invention of Logarithms in 1614.
1650 [Charles II, James II, William III, and Mary.]	Halley, 1656–1741 (England) Bradley, 1693–1762 (England)	*Riccioli*, *Hevelius*, and *Grimaldi* lay the foundation of Selenography by constructing lunar charts. *Huyghens* discovers the true nature of Saturn's Ring in 1659. *Newton*, by the publication of the "*Principia*" (1687) establishes the Unification of Celestial and Terrestrial Science, and shows *Kepler's Laws* to proceed from the action of Universal Gravitation. *Flamsteed*, whose lunar observations aid *Newton's* calculations, forms the First Modern Star Catalogue.
1700 [Anne, George I & II.]	Wm. Herschel, 1738–1822 (England) Laplace, 1749–1827 (France)	*Halley* predicts on *Newtonian Principles* the Return of the Comet of 1682, makes the first determination of Stellar Proper Motion, and the first Southern Star Catalogue. *Bradley* discovers the Aberration of Light and the Nutation of the Earth's Axis, thus laying the foundation of accurate stellar astronomy.
1750 [George III.]	Bessel, 1784–1846 (Germany) Fraunhofer, 1787–1826 (Germany) John Herschel, 1792–1871 (England and S. Africa)	*Wm. Herschel*, by his discovery of Binary Stellar Systems, shows *Newton's Laws* to extend throughout the visible universe. He discovers Uranus in 1781, and by his telescopic researches becomes the pioneer of Descriptive Astronomy. *Laplace* publishes the Nebular Hypothesis, 1796 (suggested by *Kant*, 1755), and summarises Astronomical Mathematics in his "*Mécanique Céleste*" (1799).
1800 [George IV, William IV, Victoria.]	Le Verrier, 1811–1877 (France) Secchi, 1818–1878 (Italy) Adams, 1819–1892 (England) Huggins, 1824–1910 (England) Schiaparelli, 1835–1910 (Italy) Lockyer, 1836–1920 (England) Gill, 1843–1914 (England and S. Africa) E. C. Pickering, 1846–1919 (America)	Discovery of the first two Minor Planets (Ceres and Pallas) by *Piazzi* and *Olbers* respectively about 1800. *Fraunhofer* measures and catalogues the Dark Lines in the Spectrum of the Sun and stars in 1815. *Bessel* first Measures the Distance of a Star by determining the *Parallax of* 61 *Cygni*, and furthers accurate Astronomy by his Star Catalogue, 1818, founded on *Bradley's* observations. *J. Herschel* extends his father's Survey of the Heavens to the S. Hemisphere. *Adams* and *Le Verrier* give to Gravitational Astronomy its crowning distinction by the Theoretical Discovery of Neptune in 1846, telescopically confirmed by *Galle*.
1850 [Victoria.]	Maunder, 1851– (England) Kapteyn, 1851–1922 (Holland) Lowell, 1855–1916 (America) Keeler, 1857–1900 (America) Barnard, 1857–1923 (America) Newall, 1857– (England) Turner, 1861– (England) Campbell, 1862– (America) Wolf, 1863– (Germany) Crommelin, 1865– (England) Hale, 1868– (America) Dyson, 1868– (England) Fowler, 1868– (England) Eddington, 1882– (England) Shapley, 1885– (America)	*Kirchhoff* interprets the Fraunhofer Lines in the Solar Spectrum, 1859, thus laying the foundation of Astrophysics. *Secchi* forms the first Classification of Stellar Spectra, 1863, since amplified by *Vogel* (1883) and latterly greatly developed by *Pickering* at *Harvard*. *Huggins* discovers Gaseous Nebulæ (1864) and establishes Spectroscopic determination of Stellar Radial Motion (1868). *Janssen* and *Lockyer*, by their Spectroscopic Observation of the Solar Prominences (1868) inaugurate Solar Physics, since greatly developed by *Young*, *Maunder*, *Hale*, *Fowler*, and *Deslandres*. *Schiaparelli* demonstrates the Connexion between Comets and Meteors (1866) and, with *Lowell*, develops Planetary Observation. By spectroscopic means *Keeler* demonstrates Nebular Radial Motion, and *Pickering*, *Vogel*, and *Campbell* the existence of Binary Stellar Systems. *G. H. Darwin* organises in 1877 a new departure in theoretical Astronomy by his researches in Tidal Friction and Planetary Evolution.
1900 [Victoria, Edward VII, George V.]		*Kapteyn* initiates (1904) important researches in Star-streaming, while *Shapley* and others examine the extent and Distribution of Star-Clusters. *Einstein*, by introducing his Theory of Relativity (1905), exercises a profound influence on *Gravitational Astronomy*, to test which *Dyson* (as Astronomer Royal) organises the successful Eclipse Expedition of 1919 with *Eddington* and *Crommelin*. *W. S. Adams* (of Mt. Wilson) devises a method of determining Stellar Parallax Spectroscopically, and *Hale* demonstrates the existence of a Magnetic Field in the Cyclonic Phenomena of Sunspots. *Hale* and *Pease* are the first actually to measure (1920) the Diameter of a Star (α *Orionis*) by the interferometric method. *Eddington* makes important researches in Stellar Constitution. *Russell* and *Hertzsprung* modify and extend the Classification of Stellar Spectra proposed by *Lockyer* by the introduction of the "*Giant*" and "*Dwarf*" system of *Stellar Evolution*, thus adding the factor of *mass* to temperature and density. Employment of The Statistical Method in the elucidation of *Cosmical Problems*.

OF ASTRONOMY AND ASTROPHYSICS.

INSTRUMENTAL.	GENERAL.
The Instruments known to the Ancients, viz., the GNOMON, TRIQUETRUM, ARMILLARY SPHERE, ASTROLABE, QUADRANT and SEXTANT, continue in use. *Bernard Walther* (d. 1504) introduces the use of CLOCKS in astronomical observations.	During this century Astronomy is still under the INFLUENCE OF GREEK TRADITION and is at first solely GEOMETRICAL, treating of the Motions of the heavenly bodies.
Tycho equips his OBSERVATORY URANIBORG with greatly enlarged and accurately divided QUADRANTS and SEXTANTS, and invents the method of sub-dividing the degrees on the arc of an instrument by TRANSVERSALS. *Pedro Nunez* (NONIUS), 1502–1578, suggests the sub-division named after VERNIER, who brings it into practice about 1631.	
Hans Lippershey invents the REFRACTING TELESCOPE in 1608, and *Galileo*, constructing one in 1609 for himself, applies the instrument to Astronomy, while *Kepler* improves it in theory. *Hevelius* is the last to make observations without TELESCOPIC SIGHTS, but *Gascoigne* invents the FILAR MICROMETER about 1640, and *Picard* definitely inaugurates the adoption of the TELESCOPE IN CONJUNCTION WITH THE QUADRANT.	Rise of the DYNAMIC CONCEPTION in Astronomy, which after *Galileo* is PHYSICAL, and after *Newton* GRAVITATIONAL, treating of the appearance and mutual attraction of the heavenly bodies.
Huyghens adapts the PENDULUM TO ASTRONOMICAL CLOCKS (1656), and invents the COMPOUND EYEPIECE, while both he and *Hevelius* improve definition by employing TUBELESS (" AERIAL ") REFRACTORS over 100 feet long. *Gregory* proposes a form of REFLECTING TELESCOPE in 1663, but *Newton* constructs the first in 1668, while he also becomes the pioneer of the SPECTROSCOPE by decomposing sunlight with a PRISM in 1672. *Roemer* invents the TRANSIT INSTRUMENT, and EQUATORIAL (first indicated by *Scheiner*) about 1690. PARIS OBSERVATORY erected 1671; GREENWICH OBSERVATORY, 1675, with *Flamsteed* as first Astronomer Royal.	
The REFLECTING TELESCOPE is improved by *Hadley* and *Short* (1723 and 1768), while *Graham*, *Bird*, *Cary*, and *Ramsden* are the most celebrated constructors of MURAL QUADRANTS about this period.	Rise of DESCRIPTIVE ASTRONOMY and COSMOGONY with *Wm. Herschel* and *Laplace*.
Dollond invents the ACHROMATIC REFRACTOR, 1758 (suggested by *Hall* 1733). *Wm. Herschel* advances the construction of REFLECTORS and erects his 40-FOOT TELESCOPE (of 48-in. apert.) in 1789. *Guinand* improves the manufacture of OPTICAL GLASS, 1799, enabling *Fraunhofer* to construct LARGE REFRACTORS (*e.g.*, Dorpat 9·6-inch, mounted 1824).	
Fraunhofer applies the SPECTROSCOPE to Astronomy, 1815, adapts CLOCK-WORK MOTION to TELESCOPES, 1824, and erects the first HELIOMETER, 1829. *Reichenbach*, *Repsold*, and *Troughton* effect IMPROVEMENTS IN INSTRUMENT-MAKING early in this century. *Lord Rosse* erects his GREAT REFLECTOR (72-in. aperture) at *Parsonstown*, 1845. *Draper*, *Bond*, *De la Rue*, and *Rutherford* apply the CAMERA to ASTRONOMY (1840–64), while *Huggins* employs it spectroscopically, 1863.	Rise of CHEMICAL ASTRONOMY with *Fraunhofer*, treating of the composition of the heavenly bodies.
The instalment of the PHOTOHELIOGRAPH at *Kew* in 1858 represents the first regular application of the PHOTOGRAPHIC METHOD to Astronomy (since greatly developed by *Loewy* and *Puiseux*, *Roberts*, *Wolf*, *Barnard*, *Ritchey* and others), while in 1887 *Gill* and *Mouchez* inaugurate the INTERNATIONAL PHOTOGRAPHIC CHART of the Heavens. *Steinheil* and *Foucault* propose SILVERED GLASS REFLECTORS (1856), while *Cooke* erects the first GREAT REFRACTOR (The *Newall* 25-inch, 1870), since exceeded by others culminating in the LICK 36-INCH. and the YERKES 40-INCH. (1888–1897). The EQUATORIAL COUDÉ erected at *Paris*, 1882. The ASTROPHYSICAL OBSERVATORIES of *Potsdam* and *Meudon* founded, 1874 and 1886. *Rowland* advances Spectroscopy by the introduction of MACHINE-RULED DIFFRACTION GRATINGS. *Hale* and *Deslandres* devise (independently) the SPECTROHELIOGRAPH (1889), while *Turner* introduces (1895) the employment of the COELOSTAT in connexion with FIXED TELESCOPES.	POPULARISATION OF ASTRONOMY set on foot by *Lalande* and *Bode*, while *Proctor*, *Ball*, *Flammarion*, and *Agnes Clerke* continue the work in their lectures and writings. *Royal Astronomical Society* and *British Astronomical Association* founded 1820 and 1890. During this century Astronomy gradually widens its sphere and establishes a UNIFICATION OF THE SCIENCES, by extending terrestrial and planetary gravitation to stellar systems, and by showing the essential identity of cosmical matter throughout the visible universe.
The MOUNT WILSON OBSERVATORY is established (1905) and equipped with astrophysical instruments in their latest development, *e.g.*, HORIZONTAL AND VERTICAL COELOSTAT TELESCOPES (*Snow* and *Tower Telescopes*); GREAT REFLECTORS (*60-inch* and *100-inch mirrors* by *Ritchey*); SPECTROGRAPHS; SPECTROBOLOMETERS, etc., while the usual CHEMICAL AND PHYSICAL APPARATUS of the LABORATORY is pressed into the service of Astronomy. *72-inch Mirror* mounted at *Victoria, B.C.* (1918). *Hale and Pease* apply the INTERFEROMETER to the 100-*inch Reflector* on *Mt. Wilson* (1920), and suggest a still larger instrument on similar lines for the measurement of stellar diameters. WIRELESS METHODS take their place in MODERN OBSERVATORY PRACTICE.	Modern research in the STRUCTURE OF THE UNIVERSE is greatly influenced by studies dealing with the NATURE OF MATTER itself, as well as by the PHILOSOPHICAL DEDUCTIONS drawn from the RELATIVIST VIEW OF TIME AND SPACE

395 B.C. HERAKLEIDES OF PONTUS is the first to teach the doctrine of the *Earth's Diurnal Rotation.*

300 B.C. ARISTILLUS AND TIMOCHARIS determine the relative positions of the principal stars of the Zodiac, thus preparing the way for HIPPARCHUS.

280 B.C. ARISTARCHUS OF SAMOS is the first to propound the *Heliocentric System.* (Employment of the *Armillary Sphere.*)

230 B.C. APOLLONIUS OF PERGA devises the system of *Eccentrics* and *Epicycles.*

130 B.C. HIPPARCHUS, the greatest astronomer of antiquity, establishes the science on a firm footing by his *Catalogue of* 1,080 *Stars* and his discovery of the *Precession of the Equinoxes.* He originates the science of *Trigonometry* and, by his precise observational methods, ensures accurate results. (Employment of the *Astrolabe.*)

A.D. 140. PTOLEMY OF ALEXANDRIA elaborates in his "*Almagest*," a complete compendium of all the astronomy known in his time, the *Epicycles* and *Deferents* of his predecessors, thus discarding the juster heliocentric views of Aristarchus. The *Ptolemaic,* or *Geocentric System* is dominant for fourteen centuries. (Employment of the *Triquetrum* and *Clepsydra,* or water-clock.)

After this time the Alexandrian School of Astronomy declines until after the *Mohamedan Conquest* in A.D. 642, the next advances being made by

THE ARABS.

A.D. 813. ALMAMON founds a school of astronomy at *Baghdad,* and has Ptolemy's "*Almagest*" translated into Arabic.

A.D. 850. ALBATEGNIUS, the most celebrated astronomer of the Arabs, makes accurate observations, and compiles valuable *Astronomical Tables.*

A.D. 903. AL-SUFI revises the Alexandrian *List of Stars.*

A.D. 1000. ABUL WEFA discovers the *Moon's Variation.*

A.D. 1433. ULUGH BEGH establishes a well-equipped OBSERVATORY at *Samarcand,* and compiles a valuable *Star Catalogue.*

After this time Eastern Astronomy comes to an end, but Western Europe continues the cultivation of the science introduced by the Arabs into Spain, the first advances being made by

THE MOORS.

A.D. 1038. ALHAZEN discovers the *Law of Refraction.*

A.D. 1080. ARZACHEL, of *Toledo,* publishes his *Toletan Tables,* and repeats the observations of Albategnius with greater accuracy.

A.D. 1230. The Arabic version of Ptolemy's "*Almagest*" is translated into Latin, and about

A.D. 1270. ALFONSO X OF CASTILE produces at Toledo the *Alphonsine Tables,* compiled by the best mathematicians of the Moorish universities.

The impulse thus given to Astronomy by the two latter events draws the attention of Western learning to the science, and JOHN HOLYWOOD'S (SACROBOSCO) publication of a *Treatise on the Sphere* about 1230, and NICOLAUS DE CUSA'S speculations on the *Planetary System* about 1440, prepare the way for the advent of COPERNICUS.

[*See* Chart.

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